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Commonality in Military Equipment

A Framework to Improve Acquisition Decisions

Thomas Held, Bruce Newsome, Matthew W. Lewis

Prepared for the United States Army

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Preface

In recent years, the U.S. Army has become increasingly interested in "commonality"—the sharing of common parts across different entities. Commonality has implications for procurers, designers, developers, trainers, logisticians, and users. Although usually touted as a good thing, commonality can lead to outcomes that are both negative and positive, but these outcomes are less often acknowledged or understood. They require nuanced decisionmaking.

This report assesses the consequences of commonality and provides recommendations to help enable the Army to maximize the benefits associated with commonality while avoiding the negative consequences.

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Summary

Increasingly, the U.S. Army and the Department of Defense (DoD) as a whole are developing families of systems built around common components. For instance, the Army has procured a common model of tire (a component) across multiple vehicles (systems), which previously were procured with tires that were not alike. The Army has particularly pushed for common vehicle base models and infantry weapon systems. Historical examples of each of these cases are examined in this report.[1] Common items (including systems and components) are those that are the same, to all intents and purposes, across two or more higher-level items (e.g., systems are higher level than components). *Systems* are items that are designed for discrete use, although they may be used with other items. *Components* are designed as parts of systems. Theoretically, our recommendations are applicable for any item that can be part of another item, including nonmaterial items such as training systems, or any "system of systems," a phrase that is used to describe collections of Army units and equipment or even the Army as a whole.[2]

Commonality is desirable because it can increase operational flexibility and reduce the procurement, logistical, and training burdens. It

[1] This document examines several historical examples of infantry weapons and military vehicles but does not examine projected items because much information on them remains imperfect. Therefore, we do not analyze those items under development as part of the program known as "Future Combat Systems," even though they might be more topical.

[2] "Higher-level" items are composed of "lower-level" items. For instance, components can be described as combinations of subcomponents. A separate document, Newsome, Lewis, and Held (2007), explains these levels and the concepts and definitions in more detail.

can increase operational flexibility because shared components suggest improved readiness and shared operational capabilities, such as similar distances traveled before refueling. Modular and hybrid systems, in particular, offer broader (but not necessarily deeper) capabilities. Commonality can reduce the procurement burden by reducing the number of components that need to be developed or procured. It can reduce the logistical burden by reducing the number of components that need to be stocked and the number of maintenance procedures and personnel. It can reduce the training burden by reducing the number of items for which trainees need to be trained.

However, commonality can decrease design freedom and occasionally operational capability by making different host systems share a common component, even if the common component offers more inferior performance or fewer capabilities than does a unique component. For instance, the performance of a tank that normally carries a 1,500 horsepower engine would be seriously retarded by a 500 horsepower engine that might be common across several models of lighter armored vehicle. Commonality can also increase costs for certain systems that do not need the "excess functionality" offered by a common component over a cheaper, less capable component. For instance, lighter armored vehicles would be significantly more expensive if procured with a 1,500 horsepower engine instead of a 500 horsepower engine. (Although there may be operational advantages to a more powerful engine, it could impose increased stress on the vehicle's other automotive components.) These factors suggest that commonality should be approached with caution.

To inform the Army's decisionmaking process surrounding commonality, RAND Arroyo Center was asked to assess the advantages and disadvantages of commonality and how to best manage their trade-offs. To do so, this report uses historical analysis, literature analyses, and case studies of commercial and military efforts to exploit commonality. It presents analyses of the effects of commonality on costs, capabilities, and training. It offers a decisionmaking aid that designers, developers, and procurers, in particular, could use to inform their decisions about commonality. It concludes with relevant recommendations for the Army.

What Is Commonality?

We discovered early in our project that one impediment to the Army's clearer understanding of the potential costs and benefits of commonality is the lack of a shared lexicon for commonality-related discussions. Thus, at the beginning of this effort, the project team consulted different literatures and usages in order to define a set of concepts useful for discussion of commonality (Newsome, Lewis, and Held, 2007). Table S.1 summarizes our definitions. The Introduction provides more detail on our definitions.

Operational Outcomes

The operational advantages provided by a common system depend on the type of system used, whether hybrid (combining multiple capabilities in one system), modular (allowing functions to be exchanged

Table S.1
Summary of Recommended Commonality-Related Definitions

Term	Definition
Differentiated	Altered capabilities or items
Interoperable	Able to work together
Hybrid	Having combined capabilities or items that are normally separated
Family	A functionally differentiated set of variants of a platform/base model
Modular	Capable of changing functionality through the exchange or addition of modules
Module	Exchangeable or augmentable item used to change the higher-level item's functionality
Interchangeable	Capable of exchanging places without alteration
Standardized	Meeting a standard, such as a performance or material standard or a shared process or resource
Common	Similarity across more than one higher-level item

within one system), a family (in which many or major components are shared across systems, while others remain distinct), or a differentiated system (which is distinguished by its altered components or capabilities, usually in pursuit of specialization or enhanced capabilities).

There is no single "best" option that will apply in all cases. Therefore, in all cases, objective and informed analysis will be required to determine the best option.

Hybrids

Hybrids may underperform nonhybrids for their primary functions, but this trade-off may not be significant for the hybrid's primary mission. Although hybrids are more flexible, they can introduce new operational risks. For instance, an infantry fighting vehicle (IFV) benefits from weapons that are not carried by a personnel carrier, but the IFV must expose itself to enemy fire whenever it utilizes those weapons. Since combined components or capabilities usually demand new operator skills, hybrid systems may impose increased training burdens if the operational benefits are to be realized.

Modular Systems

Like hybrids, modular systems can offer potential improvements in operational flexibility but can introduce new risks. For example, modularity may offer operators the option of leaving behind modules that are not needed for the current mission; however, the decision to leave some modules behind might leave operators without the modules they need, especially given that operational requirements can be difficult to predict. To reduce such operational risks, soldiers may elect to carry all their modules all the time, in which case the soldier might as well carry a more robust and efficient hybrid.

Families

Families of systems can increase operational compatibility between vehicles but may trade off on capabilities. For example, the main U.S. tank (the M4 Sherman) of the Second World War was a base model for a wide family of armored vehicles, but the tank itself was too small and underpowered to compete with heavier foreign tanks.

Differentiated Systems

Differentiated systems may excel at certain specialized capabilities demanding specific technologies, but they can prove inflexible. Differentiation is the preferred option if the priority is specialized capabilities or performance. However, as an item becomes more specialized, it becomes less flexible. Even if this lack of flexibility is considered acceptable when the item is first deployed, operational requirements can change over time.

Assessing the Costs of Commonality

To assess the value of commonality, the Army needs to know how the use of common items affects costs. Often greater commonality is automatically associated with lower costs. Our research shows a subtler picture. We looked at commonality's impact on the following life cycle elements:

- Component-related costs
  - Research and development (R&D) costs
  - Part costs including initial procurement
  - Inventory costs
  - Personnel costs in managing suppliers and ordering parts
- Training costs
- Maintenance personnel costs.

Component-Related Costs

Such factors as greater complexity leading to increased failure rate and excess functionality can tend to increase costs while economies of scale, greater factors of safety, purchasing power, and risk pooling can help lower costs. These factors may mean, for example, that R&D costs may be increased while inventory and repair parts costs are decreased. Further complicating the analysis is the timing of the expenses and uncertainty in future expenses. R&D costs are an up-front cost, whereas repair costs are a recurring cash stream that must be appropriately discounted through a net present value analysis and that is highly related to a future operational tempo (OPTEMPO) that is unknown. Another important consideration for the cost analyst is whether a cost is a true savings, such as a reduction in repair parts costs due to economies of scale, or an opportunity cost, such as a reduction in procurement management effort that is realized only if the number of procurement personnel is reduced. These resources may then be used for other purposes.

R&D Costs. In terms of R&D, although increased commonality will decrease the number of components that need to be developed, the cost to develop a common component may be higher than to develop a single differentiated component if the component needs to be more flexible or offer additional capabilities. If the component can be made common with one that is already stocked, R&D costs can be reduced to zero.

Procurement Costs. Procurement costs may see a net increase depending on whether there is an increase in unit costs due to "excess functionality" (i.e., the component offers capabilities beyond requirements), a decrease in unit costs due to economies of scale, or, potentially, both, with one effect outweighing the other.

Parts Costs. Parts costs exhibit similar trade-offs: The benefit will be determined by the relative magnitude of "excess capability" compared with the economies of scale. Additionally, operations and maintenance parts costs will be affected by whether reliability has been improved or reduced by the common design, which will in turn affect the usage rate of the component.

Inventory Costs. An increase in the number of common components can be expected to decrease the number of units held in inventory, thus reducing costs. This reduction can be realized when increased risk pooling reduces the variability of demands. Net inventory costs, however, may either decrease or increase, depending on the unit price effect.

Personnel Costs in Managing Suppliers and Ordering Parts. The effort to perform these activities may be reduced and simplified through a smaller supply base. Without good activity-based cost data, these costs may be difficult to estimate. Further, a reduction in "costs" is realized only if the number of personnel hours associated with supplier management is reduced.

Mechanic and Operator Training Burden

In addition to the above cost considerations, mechanic and crew training needs should also be considered when determining which components should be made common. Common components can reduce crew training and mechanic training if the uncommon components that they replace are significantly complex. For example, a common engine can significantly reduce mechanic training time, while common armaments can reduce crew or operator training time. In contrast, common nuts and bolts do not save training time, because nuts and bolts—simple components with a predictable form and function—are handled the same way even if they are uncommon.

Greater system commonality might allow some military occupational specialties (MOSs) in the Army to be consolidated. Systems that achieve greater commonality might require fewer mechanic types. The reduction in variability brought on by greater system commonality could also reduce the chances of spot shortages or excesses of MOSs.

Our review of commercial-sector firms identified several ways in which commonality led to savings in terms of training time and costs and operational gains. For example, some airlines have decided to use a single airframe or common cockpit controls and displays across planes in order to simplify the training of pilots, maintainers, and flight attendants. This decision also facilitated operations by eliminating the need to match crew qualifications to aircraft type. Significant savings can result when these benefits are multiplied across all high-value employees, such as airline pilots, in an organization.

The effects on training also depend on the trade-off between the reduction in training time per skill achieved by commonality and the need for increased cross training (i.e., the number of tasks to be trained). For example, to take advantage of the modular or hybrid benefits of a given system, it may be necessary to increase cross training if the roles performed by a particular system were previously taught only to specialist subpopulations. The number of personnel requiring training may affect the decision to hybridize or modularize.

Low-Hanging Fruit: The Best Opportunities for Reducing Costs Through Commonality

The cost elements discussed above point to four general categories of components for which it could be financially advantageous to pursue commonality.

Complex, expensive items appear to present the greatest cost opportunity by spreading the R&D cost over multiple items. For example, both commercial truck and military fleets try to reduce costs by specifying common engines. The key factor to consider is whether the cost of any excess functionality (in terms of procurement, operating, and inventory costs) outweighs the R&D and volume cost advantages.

Logistically burdensome items are another class of components that present a good opportunity for increased commonality. Large bulky items, such as tires, tracks, engines, and transmissions tend to dominate bulk storage, which can be problematic given the Army's significant storage constraints for mobile field warehouses. However, the advantages of commonality (such as reduced volume-related costs and logistical advantages) often must be traded off against the Army's desire for specialist or maximum capabilities (see the next section and Chapter Two).

High-demand items that have similar specifications are another potential common component category. Costs for high-demand items might be reduced through economies of scale, lower inventory levels, increased purchasing power, and lower order costs. Commercial research suggests these savings could be significant.

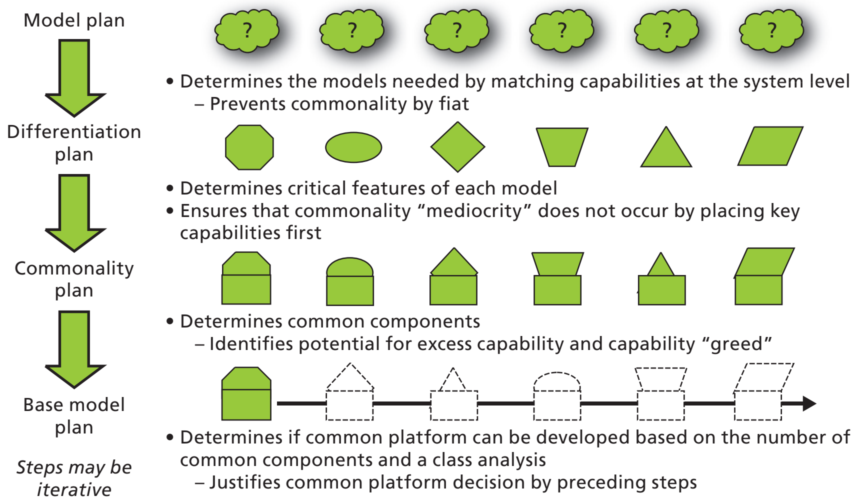
Items whose operation or maintenance are burdensome when training personnel, such as with complex software or user interfaces, should be made common in order to save on the training burden. In the text, we identify commercial companies that have insisted that user interfaces look the same across different systems so that users can be trained for just one interface.

Analytic Method to Guide Commonality Decisionmaking

As research has indicated, the process of trading off the advantages and disadvantages of commonality is subjective and imperfect. To guide designers, developers, and procurers, in particular, in their decisionmaking, we developed the decisionmaking aid shown in Figure S.1.[3] The aid includes the development of four separate plans, each of which presents an important set of decisionmaking criteria.

This decisionmaking aid provides guidance for a structured process and so is best led by objective and informed experts. The procurer can use this aid to inform the requirements and the decision to pro-

Figure S.1
Capability-Based Commonality Decisionmaking Aid



NOTE: The shapes in the figure represent the transition through the application of the decision aid from requirements with unknown physical attributes (the cloud question marks), to known features (the varying geometric shapes), to common components potentially based on a common platform (the common rectangle with varying shapes on top of it).
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[3] We based our decisionmaking aid on those in the commercial manufacturing literature, such as those by Meyer and Lehnerd (1997) and Robertson and Ulrich (1998).

cure. The designer can use this aid to choose among design strategies and balance the inevitable trade-offs during the design process. The developer can use the aid to audit the progress of development. And the logistician, trainer, and operator can use the aid to stay informed about relevant trade-offs and to determine whether designers and procurers remain cognizant of their primary concerns.

Model Plan

The designer first identifies the key capabilities needed to meet requirements and then decides which capabilities should be hybridized, modularized, or differentiated. A hybrid solution is indicated if, among other things, the key capabilities are operationally interdependent, the hybrid outperforms nonhybrids in their primary functions, the extra cost of the hybrid is less than the collective cost of nonhybrids, and the hybrid's new operational risks are acceptable. If personnel do not need all the capabilities all the time and the hybrid imposes additional costs, the system should be modularized rather than hybridized. If the hybridization or modularization would degrade critical capabilities, then differentiated models are indicated.

Differentiation Plan

The differentiation plan identifies attributes that are critical to the model's function and selects the lowest performance requirements needed to ensure the model's effectiveness.

Commonality Plan

This step identifies those components that can be made common without significantly retarding the system's capabilities. Here, decisionmaking should be guided by cost analysis, in particular. The remaining unique or "uncommon" items are then considered for interchangeability. Differentiation should be reconsidered at this stage, since cost analysis is likely to underrepresent operational impacts.

Base Model Plan

The base model plan determines whether the number or importance of common components is sufficient to warrant a base model. Although the development of a base model may be seen as an economic decision, it also has operational impacts because a base model can allow for increased operational compatibility (since variants share similar operational performance) and reduced logistics burden (since many or significant components are shared). Even at this stage, the designer should reconsider differentiation if a base model is likely to retard critical capabilities.

Recommendations

This report makes a detailed analysis of the effects of commonality on key Army concerns, primarily costs, operations, and training. It also provides a decisionmaking aid, of particular value to the procurer, developer, and designer. In addition, we make the following four broad recommendations to the Army, concerning analysis, organizational changes, decisionmaking, and training.

The Army should determine *which* specific components should be made common through objective and informed analysis. Specifically, the Army should assess existing levels of component commonality and determine where efforts should be focused to reduce costs and the logistical footprint. The Army should develop preferred commonality metrics, similar to the metrics used in this document or those used by exemplary commercial companies, to examine the existing level of component commonality in the Army and its resultant cost and logistical burden.

The Army should determine what organizational changes need to be made so that better decisions about commonality are made. We have identified several historical examples of poor military decisionmaking related to commonality, for instance by prioritizing commonality while ignoring its disadvantages, or by ignoring opportunities to procure new systems with common components. Our decisionmaking aid can only help individual decisionmakers make better decisions and does not help implement decisions. The Army should study organizational changes that would help improve decisions about commonality during the acquisitions process.

The Army should adopt a capability-based commonality decisionmaking aid, of the type discussed in Chapter Five, in order to better guide decisions about development, design, and procurement.

To help accurately assess the effects of commonality on training, we recommend the use of a structured methodology, such as the Training Impact Estimation (described in Chapter Three). Training effects can be significant but are highly dependent on the specific type of commonality under consideration and on the specific components to be made common.

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The authors were also greatly assisted in their analyses by many valuable interviews and a working group meeting with subject matter experts at the U.S. Army Infantry School, Ft. Benning, Georgia. That visit was ably organized and hosted by Robert Padin. Finally, the project team's understanding of the implications of commonality on training were informed by conversations with Neil Cramer and Michael DonCarlos.

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Abbreviations

AAV	amphibious assault vehicle
ACR	Armored Cavalry Regiment
APC	armored personnel carrier
ARS	Armored Reconnaissance Squadron
ASV	Armored Security Vehicle
ATLAS	All Terrain Lifter, Army System
ATR	Aerei da Trasporto Regionale or Avions de Transport Régional
AVLB	Armored Vehicle Launched Bridge
BCT	brigade combat team
EFV	Expeditionary Fighting Vehicle
EOQ	economic order quantity
FA	field artillery
FM	field manual
FSC	field support company
HEMTT	heavy expanded mobility tactical truck
HMMWV	high mobility multi-purpose wheeled vehicle

IFV	infantry fighting vehicle
JSF	Joint Strike Fighter
LAV	light armored vehicle
LIN	line item number
LMG	light machine gun
LMTV	light medium tactical vehicle
MOS	military occupational specialty
MTV	medium tactical vehicle
NIIN	National Item Identification Number
OPTEMPO	operational tempo
PLS	Palletized Load System
R&D	research and development
RO	requisition objective
SEE	small emplacement excavator
SINCGARS	Single Channel Ground and Airborne Radio System
SPIW	special purpose infantry weapon
SSA	supply support activity
TFX	Tactical Fighter Experimental
TIE	training impact estimation
USMC	U.S. Marine Corps
VSTOL	vertical/short take-off and landing

CHAPTER ONE

Introduction

Increasingly, the Army and the Department of Defense (DoD) as a whole are procuring or developing common "components" across different "systems." For instance, the Army has managed to procure a common model of tire (a component) across multiple vehicles (systems), which previously were procured with unlike or "uncommon" tires. The Army has pushed for common vehicle base models and infantry weapon systems in particular, some historical examples of which are examined in this report.[1] Common items (items include systems and components) are those that are the same across two or more higher-level items (systems are higher level than components). In this report, *systems* are material items that are designed for discrete use, although they may be used with other items. *Components* are designed as material parts of systems. Theoretically, our recommendations are applicable for any item that can be part of another item, including nonmaterial items such as training systems, or any "system of systems," a phrase that is sometimes used to describe collections of units and equipment or even the Army as a whole.[2]

Commonality is desirable because it can increase operational flexibility and reduce the military's procurement, logistical, and training

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1 This document examines several historical examples of infantry weapons and military vehicles but does not examine projected items because much information on them remains imperfect. Therefore, we do not analyze those items under development as part of the program known as "Future Combat Systems," even though they might be more topical.

2 Definitions of these terms and a fuller explanation of the concepts and levels of analysis used here can be found in Newsome, Lewis, and Held (2007).

burdens. It can increase operational flexibility because shared components suggest improved readiness and shared attributes. Commonality can reduce the procurement burden by reducing the number of components that need to be developed or procured. It can reduce the logistical burden by reducing the number of components that need to be stocked and the number of maintenance procedures and maintainers. It can reduce the training burden by reducing the number of items for which trainees need to be trained.

However, commonality can decrease design freedom and occasionally operational capability by making different host "systems" share a common component, even if the common component offers more inferior performance or fewer capabilities than does a unique component. Commonality can also increase costs for low-end systems that do not need the "excess functionality" (a phrase common in the commercial design literature, meaning functionality or capabilities beyond requirements) offered by a common component, rather than a cheaper, less capable component. These factors suggest that commonality should be approached with caution.

At least for major systems, there are historical examples of commonality being prioritized at some cost to other requirements. For instance, while some fighter aircraft, such as the F/A-18, have successfully served both the U.S. Navy and the U.S. Marine Corps, whose aircraft routinely operate from ships, attempts to procure a base model fighter for both the U.S. Navy and the U.S. Air Force, which does not require its aircraft to operate from ships, have been less successful. In the early 1960s, the U.S. Air Force was persuaded by DoD to adopt the F-4, which the U.S. Navy had already procured, even though the Air Force preferred a competitor. Later in the 1960s, the Navy withdrew from an interservice fighter aircraft project (Tactical Fighter Experimental or TFX), leaving the Air Force to procure the aircraft (as the F-111) at a higher cost than projected. TFX was estimated in 1961 to save $1 billion in development costs by using a common airframe to fulfill the Navy's fleet air-defense fighter requirement and the Air Force's long-range nuclear and conventional tactical fighter requirement. However, differences across the services in missions and operational environments and the resultant spread of requirements hindered development of the common system. Partly because of compromises in design, the fielded Air Force aircraft did not offer the required fighter maneuverability. More recently, the U.S. Congressional Research Service (Bolkcom, 2002) raised a concern that the projected Joint Strike Fighters (JSFs, designed for the Air Force and Navy) "are apt to be more costly than Air Force requirements might dictate, but provide less capability than the Navy might desire." Such trade-offs are not limited to the military sector. The automotive sector has found that it can take commonality too far, diluting product value and differentiation. For example, in the 1980s General Motors tried to produce a variety of commercial models from a base model, but some commercial models lacked sufficient differentiation, and their sales were poor (Simpson, Siddique, and Jiao, 2006).

An example (more recent and more pertinent to the Army) is the Light Armored Vehicle (LAV) system in Canada, where the drive for increased commonality was in part responsible for a plan to replace the Leopard tank with a wheeled LAV variant. Approximately half of Canada's Leopard tanks were removed from service in anticipation of this move. Recent operational experience in Afghanistan has forced Canada to deploy Leopard tanks there and to lease more from Germany.

These experiences suggest that to gain a significant benefit from commonality, nuanced decisionmaking is required. The Army needs to gain a better understanding of both the potential advantages and disadvantages of commonality so that it can better determine when to make commonality a key design constraint and to what degree commonality should be pursued. To inform this process, the Army asked RAND to assess the advantages and disadvantages of commonality and the trade-offs that should be considered in the commonality decisionmaking process.

Project Goals

This project sought to assess how commonality can affect the following areas:

- military capability, including both technological performance and force employment capability[3]
- life cycle costs, including research and development (R&D), procurement, operating, and inventory costs
- training, including the effects on individual and collective training needs and on repair procedures
- effects on logistics.

To examine the impact of commonality on these areas, the project team made use of historical analysis, literature analyses, and case studies of private-sector and military efforts to exploit commonality.

Using the lessons learned through this research, the project team also identified a decisionmaking aid that can be used to help guide commonality decisionmaking for designing, developing, and procuring Army systems.

Commonality Definitions and Levels

We found early on that one impediment to the Army's clear understanding of the potential advantages and disadvantages of commonality is the lack of a shared lexicon for commonality-related discussions. At the sponsor's request and based on the perceived need for such a lexicon, the project team sought to provide a well-defined set of terms for discussions of "commonality" across different literatures and usages. This effort yielded a lexicon that was documented in a separate report (Newsome, Lewis, and Held, 2007). Table 1.1 provides a list of the terms and definitions that were developed and that will be used throughout this report.

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[3] This decomposition of military capability into technological quality, force employment, and preponderance is based on Biddle (2004). As an example of why this distinction is important, a hybrid or modular infantry weapon, such as a rifle with an attached grenade launcher, may offer inferior technological performance (perhaps because the grenade launcher fires lighter ammunition) but superior force employment (because the user can fire both grenades and rifle ammunition without switching weapons) than does a more specialized grenade launcher.

Table 1.1
Summary of Recommended Commonality-Related Definitions

Term	Definition
Differentiated	Altered capabilities or items
Interoperable	Able to work together
Hybrid	Having combined capabilities or items that are normally separated
Family	A functionally differentiated set of variants of a platform/base model
Modular	Capable of changing functionality through the exchange or addition of modules
Module	Exchangeable or augmentable item used to change the higher-level item's functionality
Interchangeable	Capable of exchanging places without alteration
Standardized	Meeting a standard, such as a performance or material standard or a shared process or resource
Common	Similarity across more than one higher-level item

A common item is the same across two or more higher-level items. (A higher-level item is composed of lower-level items. For instance, a component is composed of subcomponents.) We distinguished a common item from a standardized item, which essentially meets some sort of standard. We distinguished interchangeable items, which are capable of exchanging places, since not all interchangeable items are common, even though all common items are interchangeable. We identified modules as components that are used to change the higher-level item's functionality, which is significant because the exchange of common items does not change the higher-level item's functionality. We reserved the word modular as a descriptor of systems that can accept modules.[4] We identified families as collections of variants of a

[4] Our definition of modularity, like most, allows modular systems to shed or "exclude" modules. Other work has allowed more inclusive concepts of modularity, concepts that include modular inventories and storage, for instance. Modular inventories and storage have important implications for acquisition and operations and support costs, but are more relevant for naval systems than they are for Army systems. See, for example, Alkire et al. (2007).

base model, the variants consequently sharing some common components. We identified hybrids as combined capabilities or items that are normally separated. We noted that interoperable items are any items that can work together: Some common major components, such as vehicle chassis, share attributes that allow them to work together (in this case, at least with the same mobility), but items do not need to be common to work together (for instance, some dissimilar radios can communicate with each other). Finally, we identified differentiation, referring to the alteration of items or capabilities, as an important contrast to commonality in particular.

In this report, our discussions of commonality focus on two broad categories: *systems* and *components. Systems,* such as armored vehicles or infantry weapons, are material items that are designed for discrete use, although they may be used with other items. *Components,* such as road wheels or aiming devices, are designed as parts of systems, although they may offer ancillary or unexpected stand-alone uses (such as an optical sight, which is normally mounted on a weapon but can be used independently to improve the user's vision).

Organization of This Document

The remainder of this report is organized as follows. Chapter Two focuses on the effects of commonality on operations. Chapter Three analyzes the impacts on financial costs and the training burden. Chapter Four examines the consequences of commonality for logistics. Chapter Five provides a decisionmaking aid, which is useful for designers, developers, and procurers in particular. Chapter Six presents general conclusions and recommendations for the Army.

CHAPTER TWO

The Effects of Commonality on Operations

While the motivation to make components common is driven largely by cost, commonality decisions require a broader perspective that, while incorporating cost considerations, takes into account the effects on operational capabilities. In this chapter, we ask, How will commonality affect operations? This question can be framed either positively or negatively. Will the use of a common item enhance current operational capabilities by providing new capabilities or by providing the same level of capability more efficiently? For instance, common items can improve interoperability. A common vehicle chassis suggests that variants share important aspects of mobility. Or will the use of a common item retard capability? Common components retard the performance and capabilities of some systems if those systems would gain superior performance and capabilities from more-specialized components. For instance, the U.S. medium tank (M4) of World War II was the base model for a wide family of armored vehicles, but many of these variants were outclassed by specialized foreign competitors. The tank, in particular, was outclassed by heavier foreign tanks.

In this chapter, we will not ask whether a specific common component will have operational consequences, because the question could be answered only on a case-by-case basis. Instead, we will compare the theoretical expectations of a family (of variants of a base model) with a hybrid (combining multiple capabilities or components in one system), a modular system (allowing capabilities and components to be exchanged, augmented, or excluded on one system), and a differentiated system (which offers the least commonality but the most specialization of all the comparisons).

Operational Consequences of Commonality

A requirement for common components can raise the performance and capabilities of those systems that would otherwise receive inferior components. Common components can also retard the performance and capabilities of some systems if those systems would benefit, during their primary missions at least, from more specialized components with superior performance and capabilities. A common system may dissatisfy some consumers who prefer the superior performance or capabilities of the replaced differentiated system (Perera, 1999, p. 116). This tension has been called the "standardization-adaptation balance" (Subramaniam and Hewett, 2004). (Note that these authors, like many quoted here, are using "common" and "standard" interchangeably.)

System Capability

Our analyses identified two overarching principles that should guide decisions about commonality and system design: (1) designers and procurers should understand how capability and commonality trade off; and (2) designers and procurers should understand all their design options.

Designers and Procurers Should Understand How Capability and Commonality Trade Off. Robertson and Ulrich (1998, pp. 22–23) argue that the gains attributable to commonality must outweigh the likely capability losses attributable to abandoning a differentiated system. At least at the most complex system levels, there is historical evidence that significant problems can occur when a drive for commonality to realize cost savings or operational consistency is given priority over operational capability. Some examples from the military (F-4, TFX or F-111, JSF, and LAV) and commercial (General Motors) sectors are documented in our Introduction.

Designers and Procurers Should Understand All Their Design Options. Commonality is usually conceived as an endogenous option, but the designer or procurer should compare other design options: family, hybrid, modular, or differentiated. There is no single "best" option that will apply in all cases. Objective and informed analysis by the design team will be required to determine the best option, but this analysis should be guided by a method for determining user capability requirements. An acceptable trade-off between capability and commonality (in the case of less capable common components) needs to be identified. The processes and doctrine established for existing systems may not be a good predictor of how a new technology will be used (we will discuss an example of this later in this chapter when we look at the Stoner 63A infantry weapon). User-based testing, through either rapid prototyping or simulation, is one method through which this unpredictability can be decreased.

Design Options

Table 2.1 summarizes some of the benefits and trade-offs associated with the use of the four different major design options considered here. The table focuses on both technological capability and force employment capability. We discuss these points further below.

Families. Families are collections of variants of a base model. A base model implies some operational compatibility among variants but also trade-offs in technological capabilities. Rather than specialized vehicles, differentiated by their mission and with their components tailored to that mission, variants are only as specialized as their base model allows. Sharing a base model, if the base model is significant enough, implies some operational compatibility between variants. A chassis is considered a significant component to share, since variants with a common chassis must share mobility.

Hybrids. Hybrids are more flexible than specialized systems. For instance, a tank is a "specialist" antivehicle weapon, but an infantry fighting vehicle (IFV) is both an infantry carrier and an antivehicle weapon. However, hybrids often lose the specialization enjoyed by nonhybrids. For instance, IFVs carry fewer infantry than are carried by specialist armored personnel carrier variants.

Table 2.1
Major Design Options and Military Capability

	Operational Outcomes	
Design Options	**Technological Capability**	**Force Employment Capability**
Families	Variants of base models are usually not as specialized as they could be	Commonality may increase operational compatibility
Hybrids	Hybrids may underperform nonhybrids in their primary functions Combining capabilities may involve trade-offs, although trade-offs may not be important to the primary mission	Hybrids are flexible but unspecialized Capabilities that are already operationally interdependent can be hybridized risk free, but some hybrids offer new operational risks Increased operator training breadth may be required to realize wider crew skills
Modular systems	Like hybrids, modules may underperform their specialist competitors Like hybridization, modularization can involve trade-offs, although trade-offs may not be important to the primary mission	Modules allow mission-specific customization Mission requirements are sometimes difficult to predict Like hybrids, modular systems may increase the training burden Reconfiguration is an extra training requirement, although simple interfaces reduce the burden
Differentiated systems	Differentiated systems provide specialized capabilities	These systems are specialized but inflexible

- Hybrids may underperform nonhybrids at their primary functions, although this trade-off may not be significant or may be considered acceptable. IFVs cannot carry as many personnel as an unarmed personnel carrier, and they cannot kill tanks as easily as a specialist tank can, but the features of IFVs are considered acceptable trade-offs nevertheless. Some trade-offs have been criticized as unacceptable. For example, "multirole" aircraft, which are designed to fulfill both air interception and ground attack missions, are traditionally slower, less maneuverable, and more heavily gunned when compared with specialist fighters, and they

are faster but more fragile and too lightly gunned when compared with specialist ground-attack aircraft (Walker, 1987, pp. 3–5). Multirole aircraft are increasingly popular, and some, most notably the F/A-18 and the Eurofighter, are able to offer different role capabilities (air-to-air combat, ground attack, electronic countermeasures, and even refueling in air) that sometimes outperform their more specialized predecessors. Ideally, hybrids should outperform the specialist predecessors that the hybrid is intended to replace.
- Hybrids may offer operational risks that nonhybrids do not face. IFVs must expose themselves and their carried personnel to enemy fire whenever they utilize their weapons; unarmed personnel carriers do not.
- A final problem with hybrids is that their crews must usually receive training in all the functions performed by the crews of the nonhybrids. This extra training is a burden. The wider skill set may hinder performance in individual functions.

Modular Systems. Like hybrids, modular systems can offer potential improvements in operational flexibility but can introduce potential risks:

- Modularity may provide increased flexibility to units, such as being able to reconfigure small arms from rifles to light machine guns depending on mission requirements (e.g., the Stoner 63A small arms system used in Vietnam, described in more detail in the next section).
- Modularity may also give operators the choice to leave behind modules that are not needed for the current mission; however, the decision to leave some modules behind to reduce the "mobility burden" might increase risk, especially given that operational requirements can be difficult to predict. For example, before leaving on a short daylight raid into Mogadishu, Somalia, in October 1993, most U.S. Army Rangers elected to leave behind their night sights. When the operation was unexpectedly extended, the soldiers were stranded overnight inside a hostile urban environment

without their night sights. As a result of such experiences, soldiers may elect to carry all their modules all the time, just in case. If so, the soldier might as well carry a hybrid.
- Like hybrids, modular systems also demand cross training. Reconfiguration itself is an extra skill, although simple interfaces can reduce that burden.

Differentiated Systems. Differentiated systems offer specialized capabilities and performance but may prove inflexible. Differentiation is the preferred option if the priority is specialized capabilities or performance. Armies like to operate with unmatched or overmatched capabilities. In the private sector, differentiation is a way to move out of highly competitive markets and into "uncontested market space." Armies may wish to specialize: For instance, some armies are tasked mainly with peacekeeping missions. Consequently, their equipment tends to be lighter and more mobile. However, specialization suggests unifunctionality. In this respect, differentiated systems contrast most strongly with hybrids. Differentiation also suggests uncommon components. In this respect, "differentiation" contrasts most strongly with "common."

Differentiated systems are specialized. They are designed to be more capable in their primary function than are less specialized systems. However, specialization usually entails a loss of capability in other areas. For instance, IFVs provide firepower but usually lack any amphibious capabilities, while the lighter, less top-heavy armored personnel carriers (APCs) are usually amphibious but lack heavy weapons. APCs also tend to carry more soldiers for a given size, because the total package is optimized to carry troops, whereas an IFV's design has to accommodate other capabilities. Amphibious assault vehicles (AAVs) are specialized armored vehicles used to move soldiers from ship to shore and then inland. Their length and height help provide buoyancy but make them difficult to maneuver and conceal on land (Kennedy, 2006). Similarly, the Hawker Siddeley Harrier fighter is differentiated as the first vertical/short takeoff and landing (VSTOL) jet aircraft, but this differentiation comes at a cost in speed. The specialized engine vents and the large air intakes keep the aircraft subsonic.

As an item becomes more specialized, it becomes less flexible. Even if this lack of flexibility is considered acceptable when the item is first deployed, operational requirements can change over time. Oftentimes, those changes were not originally envisioned. For instance, the inferior mobility on land of AAVs compared with APCs or IFVs has become most salient whenever the U.S. Marine Corps (USMC) has been committed to extended inland operations without amphibious landings, as occurred during the Vietnam War, the Gulf War of 1991, and Operation Iraqi Freedom (2003 and ongoing). In this context, some commentators have criticized the USMC's planned replacement for the AAV, the Expeditionary Fighting Vehicle (EFV), which dramatically improves mobility afloat but not on land (Merle, 2007).

An Infantry Weapon Example

A case study of squad small arms weapons developed in the 1960s shows the complexity of choosing between hybrid, modular, family, and differentiated weapon systems. In the early 1960s, the Army fielded completely differentiated squad weapons: a differentiated rifle (the M14), a differentiated machine gun (the M60), and a differentiated grenade launcher (the M79). It had used operational testing to help decide on its squad size and weapon mix, while experimenting with other weapons such as an antitank weapon and a 90-mm recoilless rifle (U.S. Army, 1961).

However, the Army found that the differentiated grenade launcher, in particular, created operational concerns because, although its accuracy was "excellent," placing it in a squad required the operator to be armed with only a sidearm, reducing the squad's firepower by two rifles. (The ten-man rifle squad was rearmed with two grenade launchers.)[1] As a result, the Army desired to give every rifleman both area fire (grenade) and point fire capabilities.

The hybrid that was designed to combine these capabilities, the special purpose infantry weapon (SPIW), ran into difficulties. The orig-

[1] The ratio of grenade launchers to squad members was different in the Army squad (2 to 10) than the Marine squad (1 to 14). See Weller (1966) for more on different contemporaneous weapon mixes.

inal specifications in 1962 required that this weapon be capable of both flechette (a small dart-like projectile) point fire and grenade-launching capabilities from the same trigger to achieve the desired hybrid capabilities. It was to weigh less than ten pounds when fully loaded with three grenades and 60 flechette cartridges. Computer simulation at the time suggested that these specifications, if successfully achieved, would result in a weapon that was superior to existing weapons.

However, the weapon encountered two types of difficulties: problems with the flechette-type capability and problems due to the hybrid nature of the weapon. These difficulties resulted in the weapon being inferior in both technological performance and force employment capability. The flechette round did achieve high rates of fire and excellent penetration, but the rounds could be easily deflected in flight—such as by heavy rain—and the muzzle flashes were too visible at night. Further, the flechette proved very expensive. Difficulty in achieving the hybrid requirements led one observer of the weapon to conclude that the

> "all things to all people" approach that was used in setting the requirements for this weapon had resulted in many problems that appear almost insurmountable, since many of the requirements are at odds with each other (Stevens and Ezell, 1984, p. 86).

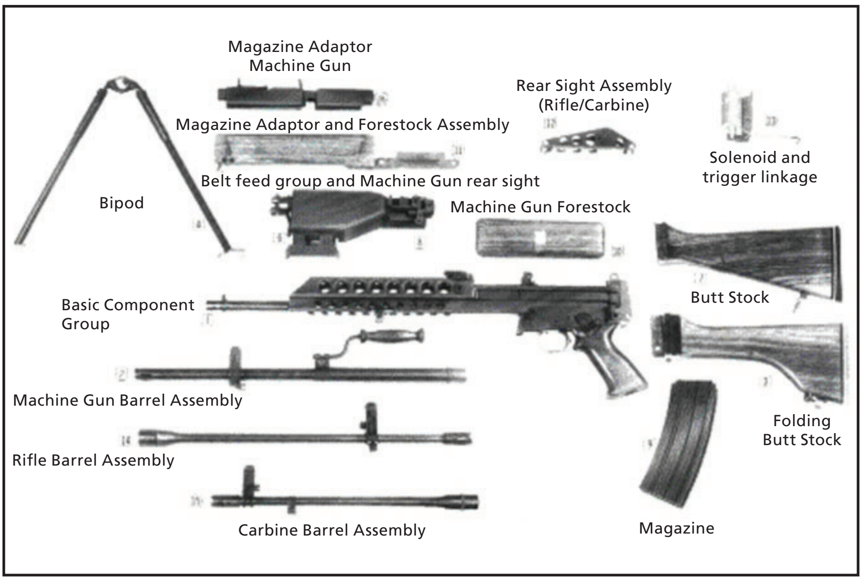
The hybrid nature of the weapon led to a weight problem, with some early versions weighing as much as 23 pounds and later prototypes still weighing 14 pounds. By comparison, the M16 with the M203 grenade-launcher weighs about 11 pounds, and three 40-mm grenade rounds add approximately 1.5 pounds. Compounding the weight problem were the weapon's bulky nature, which caused it to become entangled in brush, and its complicated operation. The weapon was plagued by reliability problems, some due to the complexity of having a single common trigger firing both types of munitions.

These problems caused the project to be "reoriented back to exploratory development" in 1966 (Stevens and Ezell, 1984, p. 224). Of note, one of the single grenade launchers developed for this project was developed into the modular M203, still in use on the M16/

M4. It is notable that the accuracy of this modular system has been reported as less than that of the specialist M79 grenade launcher, but the increased operational flexibility has resulted in its continued use, although the Marines' concern over the M203's accuracy has prompted a new search for competitive options (Eby, 2003).

A modular system developed in the 1960s, the Stoner 63A weapon system, designed by Eugene Stoner of the Cadillac Gage Corporation and shown in Figure 2.1, is an example of a modular design that offered, according to its Marine testers, both better technological and force employment capability. Stoner developed this weapon with two goals in mind. The first was to allow for a "convertible" weapon that could be reconfigured into different weapons depending on the mission. The second was to take advantage of economies of scale. He noted

Figure 2.1
Stoner 63A Weapon System



SOURCE: Images from "Stoner 63" brochure, Cadillac Gage Company, 1963.
RAND *MG719-2.1*

Used with permission of Textron Marine and Land Systems.

that traditional machine guns and rifles had been produced in a 1 to 10 ratio. By making parts of the machine gun common with the rifle, significant production economies could be gained.

This weapon used a "basic component group": a trigger assembly, stock assembly, and receiver group, plus modular barrels, stocks, and magazines. These components allowed the weapon to be reconfigured as a carbine, rifle, or varying configurations of machine guns. The rifle weighed slightly more than an M16, and its production costs were similar. Reflecting the production scale efficiencies, the machine gun costs were estimated at about two times that of the rifle, considerably cheaper than the M60 at the time, and also much cheaper than the current M249 machine gun, which is five times more expensive than the current M16 rifle (U.S. Congress, 1967). The machine gun's weight of about 12 pounds was considerably lighter than that of the M60's (18 pounds) and the M249's (15 pounds). It provided grenade launching capability through the use of a "bullet trap" type rifle grenade. This capability allowed conventional ammunition to propel the grenade rather than requiring special grenade launching cartridges, as had been the case for other grenade launching rifles. Its accuracy was reported as "phenomenal" (Anonymous, 1966). The common components for Stoner 63A variants are shown in Table 2.2.

There was considerable debate at the time concerning whether this range of weapons could be developed using a modular or family design without significant capability trade-offs. The following was the view of Colt, the maker of the M16 predecessor (the AR-15), at the time. "Colt's position is that in order to maximize the performance characteristics of a machine gun in terms of point and area fire, one must develop a machine gun and not a rifle. To this end, Colt has maintained the separate identity of its AR-15 Infantry weapon systems and the CMG-1 Machine Gun Weapons Systems" (Percy, 1965, p. 60). (The CMG-1 shared a common trigger assembly with the AR-15.)

However, testing by the Marine Corps indicated that the force employment benefits of modularity could be achieved with no apparent capability trade-offs. Both the machine gun and rifle compared

Table 2.2
Common Components for Stoner Variants

Component	Fixed Machine Gun	Light Machine Gun, Belt Fed	Light Machine Gun, Magazine Fed	Medium Machine Gun	Rifle	Carbine
Basic component group	√	√	√	√	√	√
Machine gun barrel assembly	√	√	√	√		
Folding butt stock		√	√		√	√
Bipod		√	√		√	√
Stoner or M2 tripod with cradle adaptor	√	√	√	√		
Belt feed group	√	√		√		
Butt stock		√	√		√	
Machine gun rear sight		√	√	√		
Magazine			√		√	√
Machine gun forestock		√	√			
Magazine adaptor and forestock assembly					√	√
Rear sight assembly (rifle/carbine)					√	√
Solenoid and trigger linkage	√			√		
Rifle barrel assembly					√	
Carbine barrel assembly						√
Magazine adaptor			√			

NOTE: A "forestock" is the superstructure forward of the trigger.

favorably against comparable weapons, at least in accuracy (Brant, 1965). The results of the evaluation were highly favorable:

> The basic conclusions of the evaluation are that the Stoner family of weapons provides substantial tactical and logistics advantages. There are some relatively minor modifications required prior to acceptance but none of these appears to create any problem. The system received a high degree of acceptance from personnel involved. The Stoner system is strongly recommended for adoption (Dockery, 2004, p. 296).

The weapon was field-tested for 90 days in Vietnam in 1967 by a rifle company. The force employment benefits were deemed significant by the test unit. The weapon offered "innovative changes" and "extensive" firepower (Gibbs, 2000). "[The i]nherent capability to reconstitute weapons from within a rifle company offers immeasurable physical and psychological benefits . . . . Knowing that broken machine guns can be readily repaired or even replaced from existing rifles is a great advantage."[2] Users did not report any sacrifices in weapon performance. Reliability problems did occur with the weapons, but these were thought to be unrelated to the modular design and were instead attributed to tight manufacturing. Weapon commonality allowed a rifleman with experience in the rifle to have a "sound working knowledge of the machinegun with two hours additional training."

The Stoner system was never adopted. The Marines relied on the Army acquisition process to acquire the weapon for them. From 1964 to 1966, the Army conducted extensive comparative testing of the Stoner

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[2] Following the 90-day combat trial, primarily at close quarters in jungle terrain, of the Stoner 63A, the test company was reissued standard weapons. Later in its tour, the company was tasked with securing a large piece of more open terrain. The company commander reported that he would have strongly preferred the Stoner 63A, reconfigured as a light machine gun, in the more open terrain (communication with Lieutenant-Colonel Joseph W. Gibbs, USMC (ret), October 2006). Gibbs was then company commander of the unit that carried out the combat field trials of the Stoner 63A in Vietnam in 1967. Based on a series of written questions sent to him by the authors, Gibbs consulted his leaders from that unit and provided both extensive written and telephonic responses. Those unit leaders providing input to Gibbs were Andres Vaart, 1st Platoon Commander; William Wischmeyer, 2nd Platoon Commander; Michael S. Kelly and Richard Anderson, 3rd Platoon Commanders; and Gran Moulder and Stanley Pasieka, Executive Officers.

system along with the M14, M16, and SPIW systems and reported results at odds with the Marine Corps testing. The Army reported that although there was an "operational advantage" gained through part interchangeability, it was not sufficient to merit its adoption (Army Infantry School, 1965):

> Rifle squads with the Colt weapons and squads armed with Stoner weapons are approximately equal in effect. . . . [However] because of the lighter system weight and related advantages in sustainability, rifle squads armed with Colt systems are superior. . . . The Stoner family of 5.56-mm weapons has some attractive features, but no effectiveness advantages that might warrant adoption by the Army at this time (Stevens and Ezell, 2004, p. 224).

The Army adopted instead the M16, which later received a grenade launching module, the M203. It was also developed into a light machine gun, the M249.

It should be noted that the Army testing compared the Stoner system with the other systems while holding squad organization constant, not allowing, for example, more than two machine guns per squad. Thus, its testing methods did not allow the modularity benefits to be effectively assessed. If the Army had used testing methods better designed to assess the operational advantages of modularity, the Army may have been better placed to observe the military capability benefits of the modular system, as seen by the Marines or even U.S. Navy SEALs, who adopted some Stoner models from 1967 to the early 1980s. The SEALs particularly liked the light machine gun (LMG) version, finding its light weight very appropriate for their missions. They used these weapons at times in much greater density than Army squads, at times using up to three Stoner LMGs per seven-man team. As a summary, Table 2.3 shows the small arms systems discussed, with the Army's current small arms in bold type.

Clearly, the operational effects of families, hybrids, modular systems, and differentiated systems can be significantly diverse and usually offer trade-offs that require nuanced decisionmaking. A cost-based decisionmaking process, prioritization of commonality, or analysis of commonality without considering all the design options would not

Table 2.3
Small Arms System-Level Commonality

System	Carbine	Rifle	Machine Gun	Grenade Launcher
Hybrid		SPIW—with grenade launcher		SPIW—with rifle
Modular	Stoner 63A—with rifle and machine gun	Stoner 63A—with machine gun and carbine	Stoner 63A—with rifle and carbine	**M203—with rifle** Rifle grenade—with rifle and machine gun
Family	**M4 with rifle**	**M16 with carbine**		
Differentiated		M14 M16	CMG M60 **M249**	M79

NOTE: The Army's current small arms are in bold type.

constitute nuanced decisionmaking. Further effects to consider are those on the financial costs and on the training burden, as described in the next chapter.

CHAPTER THREE

The Cost Effects of Commonality

Often greater commonality is intuitively associated with lower cost. Our research shows a more nuanced picture. We will look at commonality's impact on the following life cycle elements:

- component-related costs
  - R&D costs
  - part costs including initial procurement, repair and replacement
  - personnel costs in managing suppliers and ordering parts
  - inventory costs
- training costs
- maintenance personnel costs.

As we will discuss with respect to the component-related costs, factors such as greater complexity leading to increased failure rate and excess functionality can tend to increase costs, while economies of scale, greater factors of safety, purchasing power, and risk pooling can help lower costs. For example, R&D costs may be increased, while inventory and repair parts costs are decreased. Further complicating the analysis is the timing of the expenses and uncertainty in future expenses. R&D costs are an up-front cost, whereas repair costs are a recurring cash stream that must be appropriately discounted through a net present value analysis and is highly related to a future operational tempo (OPTEMPO) that is unknown. Another important consideration for the cost analyst is whether a cost is a true saving, such as a reduction in repair parts costs due to economies of scale, or an opportunity cost, such as a reduction in procurement management effort that is only realized if the number of procurement personnel is reduced. The resources then may be used for other purposes.

Commonality would also reduce manufacturing costs due to risk sharing, saving setup or changeover costs, and sometimes, economies of scale. Data are difficult to come by—as in any manufacturing scenario, and the Army shunts manufacturing risks to its suppliers, which pass that risk back to the Army in the form of procurement costs. For reasons of brevity, manufacturing costs are not investigated further here.

With respect to training, it is important to realize that component commonality increases do not necessarily result in equivalent training time reductions, as the underlying skills and tasks may already be similar. For example, using a common fastener as opposed to two unique fasteners may result in no training reduction because there is no difference in the skills and training times required. With respect to maintenance personnel, we will see that achieving commonality reductions require that the staffing model account for variability. As with the procurement costs, both training and mechanic costs may be opportunity costs that are achieved only if the number of trainers, training facilities, and mechanics are reduced.

Component-Related Costs

R&D Costs

Although increased commonality will decrease the number of components that need to be developed, the development costs may increase if the component needs to be more flexible or offer additional capabilities. An example of this is the Single Channel Ground and Airborne Radio System (SINCGARS) radio that was developed in the 1980s. Initially, the Air Force and the Army were pursuing separate programs for an airborne radio, each with its own R&D costs. The cost was estimated to be \$13.7 million for the Army and \$32 million for the Air Force. The cost of adding Air Force requirements into the Army program was estimated to be \$16 to \$22 million, for an overall savings of $10 to $16 million arising from a reduction in the number of R&D efforts, despite a higher total overall R&D cost (Government Accountability Office, 1985). If a component can be made common with one that is already available, development costs can be driven very low or even to zero. Both Scania and IBM report a linear relationship between R&D costs and the number of parts—i.e., as the number of parts decreases, R&D costs fall more or less proportionately (Johnson and Broms, 2000; Brockelman, Jones, and Poe, 2002).

Parts Costs

The relative magnitude of economies of scale and purchasing power compared with "excess capability" will determine the net impact of parts costs. Common components offer a decrease in unit costs as a result of production economies of scale. For instance, Scania, a Swedish truck manufacturer, estimates that production costs fall by 10 percent for every doubling of production quantities (Johnson and Broms, 2000). Greater commonality can also allow for greater purchasing power and increased competition among vendors for a common part as a result of the higher volume. However, costs do not necessarily decrease. Common components provide "excess functionality." For instance, one transportation vehicle manufacturer decided that a common electric cable design for both low-end and high-end items was too costly to field on the low-end products (Nobelius and Sundgren, 2002, p. 70). An unlike or "noncommon" part was fielded, resulting in a nearly 50 percent reduction in parts costs.

Additionally, whether or not reliability has been improved (e.g., by a design with a greater factor of safety) or reduced (e.g., through a more complex design with a greater failure rate) by the common design will affect the usage rate of the component and thus costs.

Supplier Costs

Increasing component commonality should decrease the number of suppliers. However, cost-per-supplier may increase, as suppliers become consolidated because of increased collaboration to avoid the increased potential adverse effects of poor performance from a more limited set of suppliers (Labro, 2004). Without good activity-based cost data, these costs may be difficult to estimate. Further, a reduction in "costs" is not realized unless the number of personnel associated with supplier management is reduced.

Order Costs

As we will show in an example later, using an economic order quantity (EOQ)[1] approach, combining previously separated demands, will lead to smaller orders and more frequent orders. However, the cost per order could be reduced because of process simplification achieved through a smaller supply base. Without good activity-based cost data, these costs may be difficult to estimate.

Inventory Holding Costs

Holding cost is the cost of carrying one unit of inventory for a period of time, usually one year. Holding cost is the sum of cost of capital,[2] cost of handling the inventory, cost of storing the inventory, the cost of obsolescence, and other costs such as theft and damage.[3] The cost of storing and handling the inventory may be opportunity costs in that a reduction in costs would not be realized unless distribution facilities and personnel associated with handling were reduced. Use of common components among different systems with different life cycles may result in decreasing obsolescence costs. An increase in the number of common components is expected to decrease the number of units held in inventory. This change arises from increased risk pooling and reduced relative variability of demands. These impacts can be mathematically predicted with some degree of certainty (see, for example, Chopra and Meindl, 2007). Net inventory cost, however, may either decrease or increase, depending on the unit price effect. Careful consideration of the relative magnitudes of these costs is important. For

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[1] EOQ is a model that defines the optimal quantity to order that minimizes total variable costs required to order and hold inventory.

[2] Government investment in inventory is paid for by withdrawing money from the private sector where it could be earning interest.

[3] This holding cost will vary by item since different items may have different obsolescence rates.

example, a major automobile manufacturer used over 100 separate engine wiring harnesses for each of its combinations of engines and transmissions. Each design may have a unique number of connections and lengths, designed to minimize the material cost of the individual harnesses. Consolidating the wire harnesses into about a dozen distinct harnesses would mean that each design now has some excess copper wire and some unused connectors, since a harness will need to function for more than one engine/transmission combination. However, the manufacturer found that the higher material costs were outweighed by lower inventory levels of the redesigned wiring harnesses, thus resulting in a net decrease in costs (Thonemann and Brandeau, 2000). The following example demonstrates how this benefit can be calculated.

Example of Inventory Cost Reduction: Ground Vehicle Engines

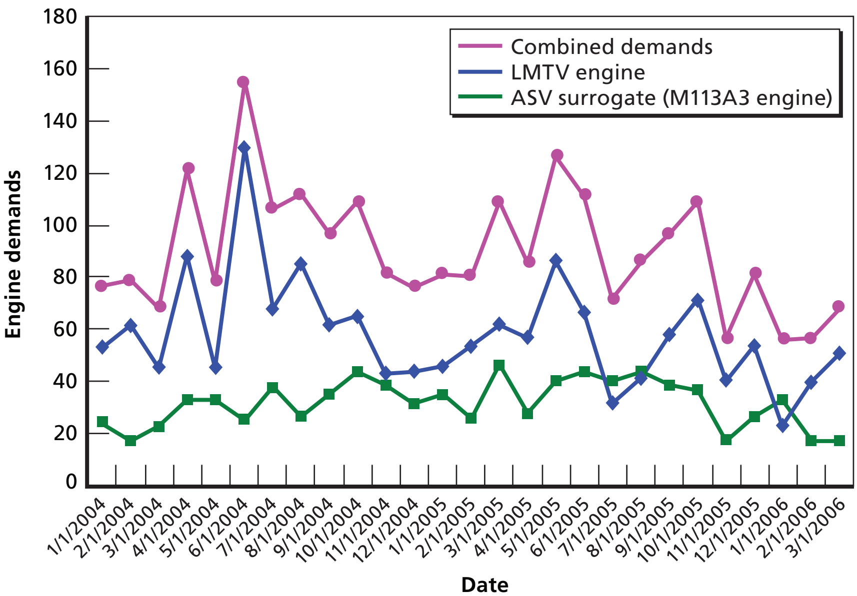
In this section, we provide an example of how component commonality can reduce inventory costs through variability reduction. We chose the engine of the M1117 Armored Security Vehicle (ASV), an uncommon engine that was recently introduced into the Army's fleet. We will examine the potential benefit of procuring the ASV with the engine in the existing 2.5-ton Light Medium Tactical Vehicle (LMTV). We first must assume that the LMTV engine can meet the requirements for this vehicle. It does have higher horsepower (275) than the ASV engine (260) but also has greater cube and weight, so some design modification might be required to use the LMTV engine. The maker of the ASV, Textron, was contacted to determine its suitability but declined because the "request is a very time consuming effort and could only be accomplished by our engineering department under a purchase order."[4]

The unit cost for each was determined through the Federal Logistics catalogue prices. Surprisingly, the higher horsepower "common" engine is cheaper than the differentiated engine at $31,232 versus

[4] Email communication with Textron Marine and Land Systems, August 11, 2006.

$33,156. To determine the reduction in the number of units, we need to determine the reduction in variability due to risk pooling. The ASV demand history was not adequate for detailed analysis, because it was only recently procured. Consequently, we used an M113A3 engine with a roughly similar fleet size[5] as a surrogate for the demand history. Figure 3.1 shows the demand streams for the LMTV and our ASV engine surrogate—the M113A3 engine. The two demand streams have significant variability. Combining or pooling the demands should reduce this variability. An examination of Figure 3.1 shows why this reduction occurs. The figure shows that in 12 of the 26 shown months, demands go up (see, for example, month 1/1/2006) for one engine and down for the other. The combined demands, then, will tend to show less relative variability.

Figure 3.1
Variability in Selected Engine Demands Across Time



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5 As noted, two engines serve the M113A3 fleet. The total fleet size numbers approximately 2,400, so half of this fleet size is 1,200 vehicles, roughly similar to the ASV fleet size.

Inventory is generally held for two reasons. First, safety inventory is carried to cover the typical variability in demand that could lead to demand exceeding the mean forecast for a given period. Second, cycle inventory exists because purchasing in large lots allows one to achieve economies of scale. Commonality will have an impact on both these types of inventory. Considering safety inventory first, establishing service levels based on the standard deviation of demand (a measure of the uncertainty of demand) is one method to determine an appropriate safety level. For example, an 85 percent service level[6] is expected to provide stock to cover 85 percent of the potential demands predicted using a normal statistical distribution. To calculate this safety level, a six-month lead time for the engines was assumed based on examination of lead times for the engines. When we combine the two engines, the standard deviation of demand over this lead time[7] is reduced from 92 to 66 (see Table 3.1).

One method to determine the cycle inventory is EOQ, a model that defines the optimal quantity to order that minimizes total variable

Table 3.1
Cost Comparison of Example Uncommon and Common Engines

	ASV	LMTV	Total Separate	Common Engine
Unit cost	$33,156	$31,232	N/A	$31,232
EOQ	19	26	45	32
Safety inventory	27	65	92	66
Average on hand inventory (1/2 EOQ + safety inventory)	37	78	115	83
Annual inventory costs	$228,000	$459,000	$687,000	$486,000

NOTE: N/A is "not available."

[6] Equal to 1.04 standard deviations of demand, based on a normal statistical distribution (see, for example, Chopra and Meindl, 2007).

[7] Calculated by taking the standard deviation of the demand over six months.

costs required to order and hold inventory, as determined using a standard EOQ formula (Chopra and Meindl, 2007).

EOQ = square root((2*C*Y)/(HU)),

where:

C = cost to place order = $2,865[8] from Army data used to calculate EOQ for all cases.

Y = yearly demands = 700 for the LMTV engine, 383 for the ASV engine, and 1,083 for the common engine.

H = holding cost = 0.188 for all cases, from Army data used to calculate EOQ. As the discussion on inventory costs indicated, commonality could reduce obsolescence costs for the common engine further, thus reducing the holding cost rate.

U = unit cost = $31,232 for the LMTV engine, $33,156 for the ASV engine, and $31,232 for the common engine.

It is interesting that the total EOQ also goes down, because the square root of the summed demand is lower than the sum of the square root of the individual demands.

We estimated the on-hand value as half the EOQ plus the safety level at an 85 percent service level. Using an 85 percent service level, the average on-hand value would be cut from 115 engines to 83.

The inventory cost savings then would be computed by multiplying the unit cost times the reduction in inventory times the holding cost. Moving to a common engine, we would expect to save approximately $201,000 per year. It is also important to note that the costs are obviously significantly affected by the annual use of the vehicle, and reductions in annual use (as would occur with a reduction in OPTEMPO) would correspondingly reduce the savings.

[8] The Army data source used was the Supply Performance Analyzer (SPA) data, which estimates the relationship between supply performance and a given funding level. SPA outputs were used in the EOQ computations.

The Best Candidates for Reducing Costs Through Commonality

Consideration of the preceding costs can be used by the Army to decide which components should be made common. As noted, case-specific analysis will be required. However, the cost elements discussed above point to two general categories of components that could be made common: complex, expensive items and high-demand items that have similar specifications.

Complex, Expensive Items: The Greatest Cost Opportunity by Spreading the R&D Cost over Multiple Items

The key factor that must be considered for complex, expensive components is whether, in making components common, the cost of any excess functionality with respect to some applications of the component outweighs the R&D and procurement volume cost advantages. Excess capability costs can increase procurement, operating, and inventory costs.

One example of a complex component for which commonality can be cost-effective is an engine. We found that for both commercial truck and military fleets common engines were attempted to be specified. Commercial truck and school bus manufacturers, such as Scania, allow for a variety of power plant configurations. Mowag, the maker of the Piranha III LAV, which is the basis for the U.S. Army's Stryker vehicle, offers five options for the power plant and transmission so that client militaries can choose an engine common with those in vehicles already held in the inventory. The Israeli Army has chosen to replace engines in older vehicles, such as vehicles based on the Centurion and M60 tank chassis, with the AVDS-1790 engine, which is also installed in Merkava tanks.

High-Demand Items That Have Similar Specifications

This category presents an opportunity to reduce costs through economies of scale, lower inventory levels, increased purchasing power, and lower order costs. Commercial research suggests that these savings could be significant. i2 Technologies US, Inc. (2004) estimates that between 30 and 40 percent of a manufacturer's parts are duplicates or have acceptable substitutes. Making these components (for example, nuts, bolts, and electrical components) common would not require any modification to the system, so long as they could serve different systems with similar tolerances within the range of a component's capability.

Effects of Commonality on Training Costs

There are a number of areas in which commonality could affect training of individual operators and mechanics. This section begins with a brief review of where commercial firms have found commonality to affect training. It then presents a framework for understanding the trade-offs and general predictions regarding training benefits, supported by relevant theories of skill acquisition. A method for assessing the training effects of commonality on individual skills is then presented and applied to a case study of small arms. Training costs and benefits associated with commonality are reported for time and other training resources.

Training Impacts of Commonality in the Commercial Sector

The potential savings in training time and dollars from developing and fielding equipment with common attributes is well understood in the commercial world, especially where training costs are high, such as for airline flight crews.[9] Southwest Airlines' decision to fly a fleet with a single airframe, the Boeing 737, simplifies the training of pilots, maintainers, and flight attendants (Treacy and Wiersema, 1994). This training advantage is so important that the company will reject changes that reduce commonality. For example, "in more recent models of 737s, Boeing designed a 'glass cockpit' with computer screens replacing old-fashioned analog dials. But in order to maintain interchangeability, Southwest asked Boeing to program the new displays to look like the 'old steam gauge' dials and indicators that are so familiar to Southwest

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[9] Personal communication with N. Cramer, manager of instructional systems, Northwest Airlines, January 3, 2007.

pilots" (Sheffi, 2005). Similarly, the common cockpit controls and displays across the Airbus A-320, A-330, and A-340 airliners are supposed to save 20–25 percent in pilot training costs (McManus, Haggerty, and Murman, 2005). An Italian-French based aircraft manufacturer claims (Aerei da Trasporto Regionale or Avions de Transport Régional [ATR], n.d.) that its ATR 42 and 72 "family" of aircraft reduces training costs and increases "aircrew productivity," with savings of $150,000 per year, per aircraft.[10]

Not only can training savings be gained, there can be operational efficiency gains as well. For these aircraft and airline examples, improved crew scheduling (no need to match the specific crew qualification to aircraft type), reductions in spare parts inventories, and reduced design/manufacturing costs are also valued. Boeing sought to reduce development costs and provide savings in training and requalification to purchasers when it designed the 757 and 767 at the same time with identical cockpits. Even the toy retail chain Toys "R" Us reportedly designs stores with similar floor plans so that associates can move between stores without retraining.

When considering how to reduce the training "footprint," corporations know well that small changes can mean significant savings. Airlines want their highly paid aircrews to spend as little time as possible away from flight operations while they are being trained or requalified. To reduce training time, Northwest Airlines reportedly changed the design of the preflight checks of instruments in the cockpit to be similar across different Boeing aircraft, hence reducing the training burden on pilots qualifying on new Boeing aircraft.[11] Such redesign might save as little as only one hour of training time per individual, but, across high-value employees over time, such savings can be significant.

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[10] ATR's claimed savings include "less new-type training cost and time, higher crew productivity, and easier crew scheduling and standby . . . [a]ssuming a mixed fleet of 10 ATR-500 as opposed to an equivalent fleet composed of different aircraft with no commonality" (ATR, n.d.).

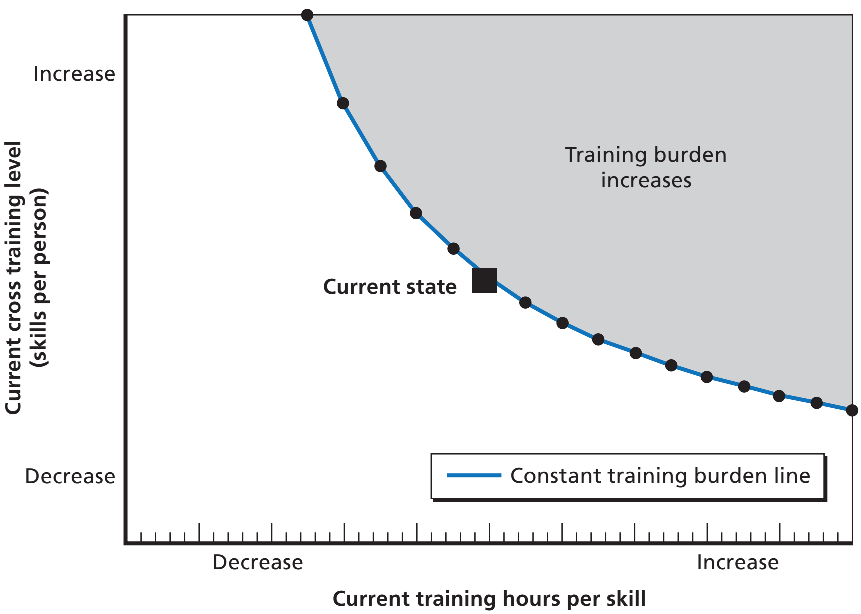
[11] Preflight checks of instruments at Northwest Airlines are called a "snake" for the standard pattern that is traced around the instruments in the cockpits (personal communication with M. DonCarlos, Northwest Airlines pilot, July 8, 2006).

In sum, commonality of systems can provide significant training cost and burden returns to corporations. These savings can be seen for operational as well as for maintenance staffs. As noted, there are also operational advantages that can be gained from training commonality.

Training Impact Assessment and Organizational Design

Figure 3.2 shows two determinants of training time that must be considered to understand the effects of increased commonality: training hours per skill and the present degree of cross training in an organization. The present degree of cross training could be viewed as the number of skills, on average, that a mechanic or operator possesses and for which they have to be trained. (Hybridization and modularization usually increase cross-training requirements because the personnel are

Figure 3.2
Notional Training Impact as Determined by Training Time Per Skill and Degree of Cross Training



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called upon to execute a broader range of tasks.) Total organizational training burden per person, then, is the average number of training hours per skill multiplied by the average number of skills per person. A "constant training burden line" is shown to indicate the relative tradeoff between increased cross training and the reduction in training time per skill necessary to keep the training hours constant. Below the line, training burden will decrease. As the chart shows, if cross training is increased in a way that outweighs the training hour per person reduction achieved by commonality, total training hours will increase.

The average number of skills per person in which an organization trains an individual is an organizational choice. Below we present an example of differing degrees of cross training as shown in the differing consolidation of mechanic military occupational specialty (MOS) across the U.S., Canadian, and British armies. The Canadians have chosen to cross train their mechanics on all vehicles, whereas the British have split their training into three types of mechanics; the U.S. Army carries six types. As noted, this increased cross training (without, at least in the case of the British, increased commonality that could lead to a reduced time to learn each skill) has come at an increased investment in training hours. The increased training hours necessary to achieve this cross training must be balanced against the benefits in capability and flexibility. This relative degree of cross training is important in assessing the impact of commonality, because if we want to take advantage of the modular or hybrid benefits of a given system, we may have to increase the degree of cross training if these roles were previously filled only by certain specialized personnel.

A hybrid system may in fact "force" an organization to provide increased cross training. If the current set of differentiated systems is already supported by a common mechanic or operator, the level of cross training will be unaffected. As we will see later, the training hours per skill may be expected to decrease as component commonality increases. Depending on the existing level of cross training, an organization could choose to harvest the entire savings (as in the example of Southwest). It may also choose to forgo some of the savings and instead "invest" them in increased cross training, as we will consider in the small arms example later. The net training burden impact in this case is not clear, because the reduction in training time per skill needs to be weighed against the increase in cross training.

Models of Skills and Skill Acquisition in Training/Education and Probable Areas of Training Savings Per Skill

Models of skill acquisition exist that seek to capture both how simple knowledge of facts and procedures (i.e., the steps in a task and how to carry out those steps in sequence) are acquired and how more complex, expert skills carried out in real time, under stressful conditions, are acquired (Anderson et al., 2004; Laird, Newell, and Rosenbloom, 1987; Klein, 1998; Klein and Baxter, 2006). For simple skills, such as those dealt with in the context of small arms operation and maintenance, models make predictions about skills and transfer of savings based on "identical elements" that two different skills share (Singley and Anderson, 1989). For more complex skills, Klein's "recognition-primed decision-making" model (Klein, 1998) seeks to capture the deep knowledge of experts and their expertise at quickly assessing situations and taking appropriate actions and the links of that knowledge to rich, underlying "mental models."

The skills investigated in the accompanying case study of commonality training effects are not complex decisionmaking skills, but instead are the skills and procedures of basic and advanced marksmanship across different weapons. Hence, the assumption of transfer of "identical elements" of procedures will provide a sound framework for predictions about training time savings. Although the term "identical" would imply that the conditions for application of a skill are exactly the same, this theory does also provide for near-matches with respect to the conditions of skill application and actions that need to be taken. For example, if two weapons are very similar on critical dimensions, (e.g., the M16A2 and the M4, variants of the M16) then there would be a large transfer of skills from one weapon to the other without the need for specific training. In sum, and not surprisingly, the models predict that the greater the number of features shared by the two pieces of equipment, the larger the savings when teaching the operation and maintenance of the second piece of equipment.

Training Impact Estimation (TIE) Methodology to Assess Training Impacts of Commonality for Army Systems

Although we found in the literature examples of methods used to evaluate the impact of commonality on component-level costs, we did not find examples of any standard methodologies to evaluate training effects. The examples of estimation we found appeared to be simply based on asking subject matter experts how much training time would decrease (see Nuffort, 2001) and resulted in unsupportable results. Nuffort reports estimations of reductions of 75 percent in mechanic training costs due to “increased” commonality. But at what level of commonality? Further, a given percentage increase of commonality might not result in a corresponding decrease in training costs. Because of this lack of structure, we developed a methodology, called TIE, to more accurately determine the effects of commonality. This process consists of six steps:

1. Identify existing systems that are analogous in operation to the new proposed system(s).
2. Identify the type of commonality that is expected in the new system, e.g., component or system, and map the attributes of the existing systems onto the new system as closely as possible:
   – the components that are common
   – the importance of those common components to operation of the new equipment.
3. Identify the type of component or system commonality sought, e.g., hybrid, modular.
4. Identify the training tasks associated with training the existing system(s) and the times that these take for the differentiated equipment.
5. Conduct a subject matter expert review of the specifics of the training to assess where there are
   – overlaps of existing tasks/training that can be eliminated
   – missing tasks/training that must be added.
6. Start with the base times for the differentiated equipment, subtract the common times, and add the missing times.

The same method could be modified and used to assess the effects of commonality on training of maintainers.

The next subsection describes an application of this method to a small arms example.

Example from Small Arms: A Case Study Assessing Hypothetical Training Effects from Differentiated Versus Modular Rifles and Light Machine Guns

As an example of the type of analysis that could be done to assess the training hour impact, we will examine the effects on training of a modular rifle and light machine gun. As discussed previously, two key determinants need to be considered: the impact on training time per skill and the potential change in cross training or number of tasks to be trained. We will first discuss the methods used to determine the impact on training time per skill.

As discussed, unlike parts, where distinct part numbers necessarily indicate a level of differentiation, the impact of common components on training time requires expert analysis. A panel of small arms training experts (drawn from the Army Infantry School, Fort Benning, Georgia, for the purposes of this analysis) thought that the savings would be dependent on common critical components, such as the gas mechanism, operating rod and springs, sights, feed, and specific round (not just bullet—some rounds cannot be shared because of differences in cartridge size and powder charge). Therefore, to assess the training hour impact we applied the TIE method described in the previous section using the expertise of small arms experts at the infantry school in Fort Benning. The method includes having the expert panel review the training instructions in relevant Training Support Packages (TSPs)[12] for selected training and determining which training steps could be made common given the specified level of critical component commonality.

In the case study, we compared the current Army rifle (M16) and light machine gun (M249) to a hypothetical modular rifle and

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[12] For instance, TSP number 071-D-2053(BCT)/BRM 1 (Basic Rifle Marksmanship), August 1, 2006.

machine gun system. We defined the hypothetical modular system to be very similar to the rifle and LMG variants of the Stoner 63A system (see Chapter Two). The details of this hypothetical system were laid out and discussed with the expert team as part of applying the estimation method. Note that training for small arms takes place both during basic training and twice yearly at the units. The basic training for the M249 is largely familiarization training, while the M16 training is more extensive. At the unit, soldiers are trained on the M249 only if they have been assigned that weapon. Table 3.2 summarizes the results of the application of the estimation method.

As the table shows, basic training hours are not significantly affected because most weapon training during basic training is rifle training. Significant training time is saved in the unit training of assigned weapons with respect to time per task and total time for all tasks. However, the full operational benefits of modularity require increased cross training, e.g., "every rifleman an LMG gunner." Given the savings in unit training time per person that are shown in Table 3.2, the number of LMG gunners could be increased up to 2.5 times (since the modular machine gun requires only 9.5 hours of training time, compared with 23.7 hours for the M249), without increasing the unit training burden compared with the differentiated case. However, this increase in cross training would still not be sufficient to cross train all members of the squad in LMG, because the cross training would have to increase by a factor of four to cover all members of a team. Hence, to obtain full cross training in LMG would require an increase in the total training hours for the unit despite the commonality training benefit at the individual level. Ammunition costs would also increase in order for additional personnel to qualify on the weapon.

Table 3.3 details the Army-wide impact. The table extracts the findings from Table 3.2 on training times and also adds in the potential impact on rounds. Looking at both the rounds and training time, we see that the training burden may increase or decrease, depending on how the common system is used. For example, in modular unit qualifications, we see that the reduction in training time could cause the hours to go down (green font), whereas increasing the number of individuals to be trained could cause the hours to go up (red font).

Table 3.2
Modular Training Impact

Basic Training Times				
	Hours Per Category			
Category of Training	M16	M249	Modular Rifle	Modular LMG/MMG
Introduction, disassembly, and assembly	5	3.1	5+0.086[a]	0
Preliminary marksmanship training	32		32	0
Downrange, record, "trainfire," night, and other firing	40	1	40	1
Total	77	4.1	77.086	1

Unit Training Times			
	Hours Per Category		
Category of Training	M16	M249	Modular LMG/MMG
Introduction, disassembly, and assembly	4 (0)[b]	3	1
Preliminary marksmanship training	12	4.2	0.5
Downrange, record, "trainfire," night, and other firing	37	16.5	8
Total	53	23.7	9.5

SOURCES: For unit estimates except where noted: Field Manuals (FMs) 3-22.9 and 3-22.68.

[a] SMEs added 5 minutes (0.086 hours) to the "correct malfunctions" step.

[b] U.S. Army Field Manuals recommend 4 hours; SMEs estimate 0 hours.

Using estimated values for the number of soldiers in basic training and the number of M249s per brigade[13] results in a training savings in basic training of approximately 400,000 hours per year and a

[13] We estimated 130,000 trainees in basic training each year. There were 220 M249s reported in U.S. Army, 2004. The number of M249s varies somewhat by unit type.

Table 3.3
Systemwide Training Time and Round Impact

	Basic—One Time (number of hours)	Unit Qualifications—Twice Yearly (number of hours)
Training Time		
M16	$77(n_{IMT})$	$53(n_{Army})$
M249	$4.2(n_{IMT})$	$23.7(\Delta_{LMG} * n_{Army})$
Modular rifle/LMG		
Independent roles	$77(n_{IMT}) + \Delta_{modbt} * 4.2(n_{IMT})$	$53(n_{Army}) + (\Delta_{modut} * 23.7)(\Delta_{LMG} * n_{Army})$
Cross-trained roles	$77(n_{IMT}) + \Delta_{modbt} * 4.2(n_{IMT})$	$53(n_{Army}) + (\Delta_{modut} * 23.7)(n_{Army})$
Number of Rounds		
	Basic—One Time (number of rounds)	**Unit Qualifications—Twice Yearly (number of rounds)**
M16	$385(n_{IMT})$	$196(n_{Army})$
M249	$100(n_{IMT})$	$288(\Delta_{LMG} * n_{Army})$
Modular rifle/LMG		
Independent roles	$385(n_{IMT}) + \Delta_{modbr} * 100(n_{IMT})$	$196(n_{Army}) + (\Delta_{modur} * 288)(\Delta_{LMG} * n_{Army})$
Cross-trained roles	$385(n_{IMT}) + \Delta_{modbr} * 100(n_{IMT})$	$196(n_{Army}) + (\Delta_{modur} * 288)(n_{Army})$

NOTES: The training burden may increase or decrease, depending on how the common system is used. For example, in modular unit qualifications, the reduction in training time could cause the hours to go down (green font), whereas increasing the number of individuals to be trained could cause the hours to go up (red font).

n_{IMT} = Number of soldiers in basic training.

n_{Army} = Number of soldiers in Army qualifying on the use of the rifle.

Δ_{LMG} = Percentage of rifle soldiers qualifying on LMG.

Δ_{modbt} = (modular LMG training time/M249 training time) in basic training.

Δ_{modut} = (modular LMG training time/M249 training time) in unit.

Δ_{modbr} = (modular LMG rounds/M249 rounds) in basic training.

Δ_{modur} = (modular LMG rounds/M249 rounds) in unit.

unit training savings (at the brigade level) of 3,100 hours per year with no changes in the number of personnel trained with the LMG.

Conclusions Regarding Training Impacts of Commonality for Army Systems Development

Based on the application of the TIE method in this simple small arms case, design commonality appears to offer potentially significant reductions in the training of later, "assigned" weapons in a hypothetical modular weapon system. However, those training savings would not arise during initial entry training, but instead arise in unit-level training. Although there may be other operational effects of commonality, such as the ability to make every rifleman a light machine gunner, this operational capability would come at the cost of additional training tasks for every soldier, as well as ammunition costs, increasing the overall training requirement.

More generally, the analysis provided a method (TIE) for making predictions of the training impacts of commonality. This method is strongly reliant on the judgments of subject matter experts who are provided with detailed information about the assumptions made in moving from current training on current systems to estimates of training with a new system.

Items whose operation or maintenance is burdensome to train, such as complex software or user interfaces, should be made common in order to save on the training burden. In this document, we identify commercial companies that have insisted that user interfaces look the same across different systems so that users can be trained for just one interface.

Impact of Commonality on Maintenance Personnel Costs

Because personnel costs are a significant portion of operating costs, it is important to consider the impact of commonality on them. The Army has many different types of mechanics. Greater system commonality could allow the number of MOSs in the Army to be consolidated. As pointed out in the earlier engine example, commonality's primary benefit with respect to total inventory lies in reducing variability. Unfortunately, the existing staffing model would not allow this benefit to be captured. In the existing staffing process for U.S. Army mechanics (i.e., the mechanic inventory),[14] demand variability with respect to repairs is not included, so when we examined the impact for sample units we did not see much of an effect in reducing the number of mechanics in a particular unit through MOS consolidation. If demand variability were included, we would expect to see reductions in the number of mechanics similar to those we saw in the ASV engine example, due to a consolidated MOS. The separate mechanic MOS could be viewed as analogous to different engines. The demand for different mechanic types may vary by month similar to variations among the different engines. Combining the mechanic types could reduce this relative variability and thus the number of mechanics that need to be "stocked" to meet this demand variability.

Increased commonality facilitates MOS consolidation through reduction of the needed training burden as indicated earlier in the discussion on training. Therefore, commonality is the only way to achieve this consolidation that increased training could be given as well. This statement can be proven by looking at those foreign militaries that have fewer mechanic types than the U.S. Army has. The Canadian Army, which albeit has less breadth of equipment than the United States, has just one mechanic type (vehicle technician) for repairs to vehicles, generator, heaters, and other powered equipment. The UK, which has a similar breadth of equipment to that of the United States, uses three mechanic types to service and recover all its vehicles:

- Vehicle mechanic (A)—heavy tracked armored vehicles
- Vehicle mechanic—light tracked and wheeled vehicles
- Recovery mechanic.

The U.S. Army has many more different types of mechanics. For example, the Maneuver Forward Support Company (U.S. Army, 2004), described in Table 3.4, has six different MOSs servicing vehicles and three others servicing other types of equipment:

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[14] MOS requirements per unit equals (equipment density) times (annual maintenance hours per line item number [LIN, a part number] per MOS) divided by (available maintenance hours per year).

Table 3.4
Location and Type of Mechanics for the Maneuver Forward Support Company

	Field Maintenance Company	ARS FSC	Maneuver FSC (2)	FA FSC
Supervisor	52D-1 63B-1	63M-3	63A-2 63B-1	63D-2
Senior mechanic	52C-1 52D-1 63B-2	63B-1 63H-1 63M-3	52C-1 52D-1 63B-1 63A-2 63M-3 63H-1	52D-1 63B-1 63D-2 63H-1
Mechanic	45 Total 52C-1 52D-4 63B-31 63H-3 63J-6	43 Total 52C-1 52D-4 63B-15 63H-11 63J-3 63M-9	68 Total 52C-1 52D-4 63B-17 63H-10 63J-4 63M-18 63A-12 62B-2	37 Total 52C-1 52D-7 62B-1 63B-15 63H-2 63D-10 63J-1
Technical inspector	63B-2	63B-1	63B-1 63H-1	63B-1 63H-1
Recovery supervisor	63B-1	63H-1	63A-1	63D-1
Recovery operator	63B-3 63H-2	63B-3 63H-8	63B-3 63A-8 63M-10	63B-1 63D-6

- 62B: construction equipment repairer
- 63A: M1 Abrams tank system maintainer
- 63B: light-wheel vehicle mechanic
- 63D: artillery mechanic
- 63H: track vehicle mechanic
- 63M: Bradley Fighting Vehicle system mechanic
- 52C: utilities equipment repairer
- 52D: power generation equipment repairer
- 63J: quartermaster and chemical equipment repairer.

The foreign militaries achieve their mechanic-type reduction through increased cross training, which requires more training time, with Canada providing 30 weeks and the UK averaging 27 weeks of initial training, compared with an average of about 12 weeks for the U.S. Army.[15]

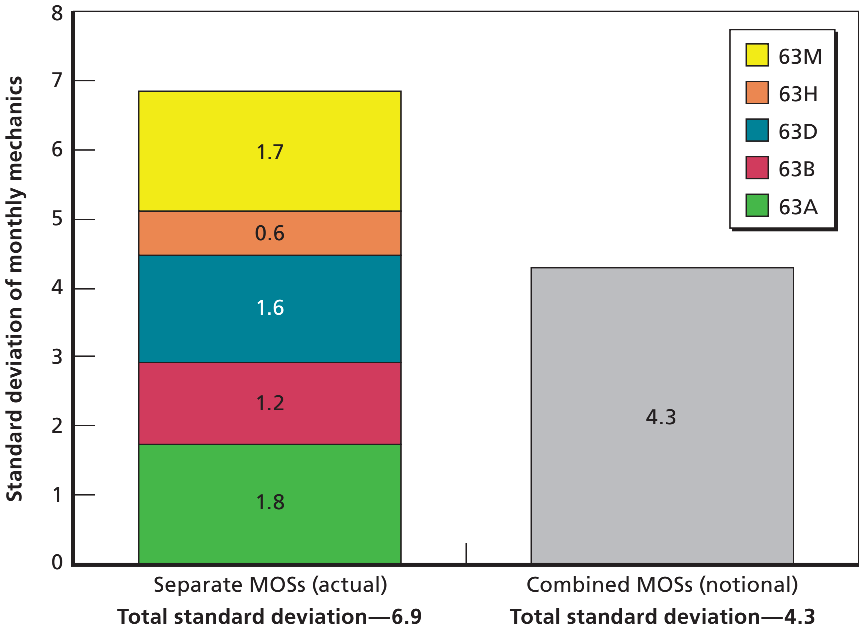
Supply variability, influenced by recruiting, training, and retention, can result in significant spot shortages in units of some low-density MOS types. For example, if the table of organization and equipment calls for an inventory of one or two persons with a given MOS, a shortage of one person is significant. This effect of supply variability would be reduced if the MOSs were combined.

Figure 3.3 illustrates the potential effects of this supply variability reduction using a sample unit that includes mechanics who have the following MOSs: 63A, 63B, 63D, 63H, and 63M. The figure shows the combined standard deviation for the number of mechanics with a certain MOS at an actual sample unit for both the existing separate MOS and a fictional combined MOS. As the figure indicates, the standard deviation for the combined MOS is almost half that of the separate MOS on the left, reducing the standard deviation from 6.9 to 4.3.

As this chapter has shown, the decision to increase commonality requires case-specific analysis of each type of cost. Uncertainties regarding demand patterns require sensitivity analysis.

[15] Canadian training times from Canadian Army, 2007. UK training times from British Army, n.d. U.S. times from U.S. Army, n.d.

Figure 3.3
The Effect of a Combined MOS on Mechanic Supply Variability



SOURCE: U.S. Army, October 2004 to September 2005, for the 3rd Armored Cavalry Regiment (3ACR) unit.

NOTE: The unit averaged 25 63As, 15 63Bs, 6 63Ds, 6 63Hs, and 26 63Ms over the period shown.

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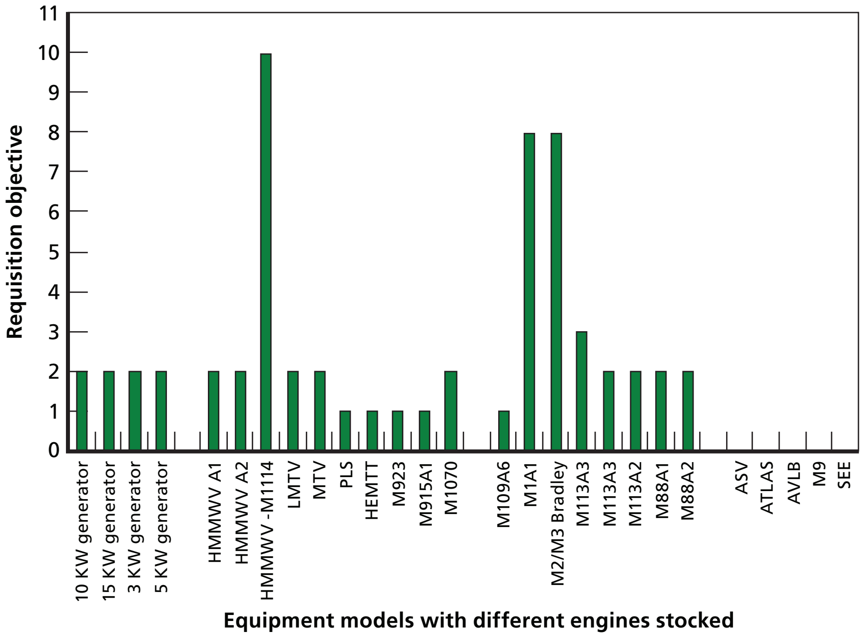
CHAPTER FOUR
The Effects of Commonality on Logistics

Logistically burdensome items are a class of components that often present a good opportunity for increased commonality. As we saw in the cost chapter, increasing commonality will generally result in a lower level of inventory. This general result is especially important for the Army, because mobile field inventory storage constraints in each brigade combat team (BCT) and support brigade are significant. Large bulky items, such as tires, tracks, engines, and transmissions tend to dominate a unit's bulk storage. The key factor that must be considered for these components is whether the cost of any excess functionality negates the volume-related cost and logistical advantages of making a component common.

The benefit of component commonality in reducing the logistics burden is shown in Figure 4.1. The figure shows the requisition objective (RO) values, by weapon system, for engines carried by one illustrative supply support activity (SSA) supporting a heavy brigade combat team. The RO is the maximum quantity of an item authorized to be on order or on hand at any time. Comparing RO values can show the relative logistical impact of stocking similar or different engines. This SSA has to carry more than 20 different engines for the wide fleet that it supports. Engines are heavy and require significant storage space; hence, they have significant effects on the SSA's footprint and transportation assets. In fact, an SSA might not be able to carry some low-demand engines, such as the ASV's engine, because of lack of commonality: The SSA may lack the space to store the extra engines or the lift to move them. Assessing the specific effects at a specific SSA

Figure 4.1
RO Levels for Engines at a Heavy BCT

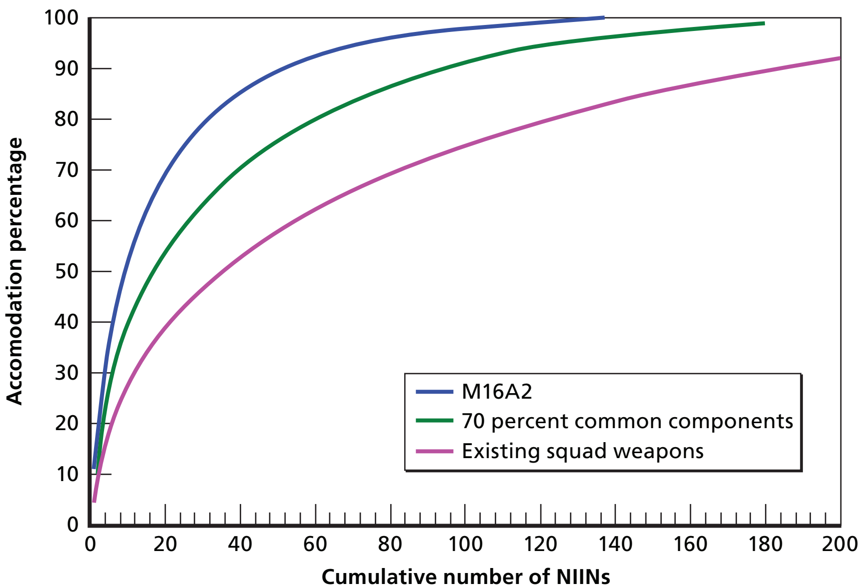


RAND *MG719-4.1*

would require examining the demands for the specific National Item Identification Numbers (NIINs). As a rough estimate of the reduction in inventory, some companies, such as Hewlett Packard, estimate that for equal demand, independent and normally distributed components, inventory levels are reduced by 1 – 1 over the square root of the number of components to be made common. As an example, making two equal demand components common would reduce the inventory levels by about 29 percent (1 – 1/(square root(2)). Use of a common engine could also either reduce the local logistical burden or increase demand enough so that it is stocked.

For some components, however, the logistics benefits may not be significant even if the number of needed parts is reduced significantly. As an example, Figure 4.2 shows the cumulative number of parts

Figure 4.2
Component Commonality Example



SOURCE: ISO Group, n.d.
RAND *MG719-4.2*

necessary to achieve a given level of accommodation[1] for deadlining[2] requests for different small arms systems. This example shows the benefits of system-level commonality in reducing the number of parts. Thus, for the combination of the existing squad weapons of the M4, M16, and M249, about 80 parts are needed to reach 70 percent accommodation. If a modular family system were used, then about 39 parts would be needed to achieve this level of accommodation.[3]

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1 The accommodation rate is defined as the percentage of requests for items that are on the stockage list, whether or not the requested item is immediately available.

2 A "deadlining" part request is a high-priority requisition for a part that has caused a vehicle or system to be reported as not "mission capable" and hence requires the unit to report it as part of its readiness reporting.

3 This figure is determined by interpolating 70 percent between the M16 curve and the existing squad weapons curve, the number of NIINs to reach a certain deadlining percentage. The 70 percent estimate was used because the M4/M16 family has approximately

However, this dramatic reduction in parts does not produce great benefit, because the relative logistics burden of these parts is small, with total cube and weight for small arms parts for a given SSA supporting a BCT being less than total cube and weight of a single M1A1 tank engine, for example. However, the benefits in enabling greater supportability still exist.

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80 percent commonality and an examination of the parts on the M249's potential to use common parts similar to those on the Stoner showed that approximately 60 percent of the parts weighted by the deadlining percentage could be made common. Seventy percent was used as an average of these values.

CHAPTER FIVE

An Aid to Commonality Decisionmaking

As the research has indicated, commonality decisions cannot be viewed simply as a choice between commonality or not, or between low costs or high costs. Common components have effects on operations, as noted in Chapter Two, on costs and the training burden, as noted in Chapter Three, and on logistics, as noted in Chapter Four. These effects are imperfectly competitive, meaning that no choice is clearly optimal. The effects are better conceived as trade-offs. Decisionmakers are faced with the subjective task of deciding which trade-offs are acceptable.

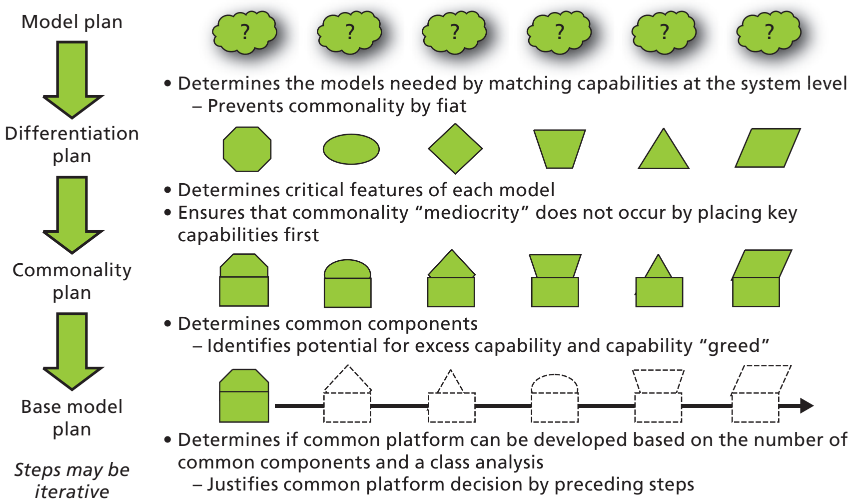
The commercial manufacturing world faces these decisions and trade-offs as well and has increasingly turned to decisionmaking aids during the design and procurement stages in particular (although these aids can be used at any time to check the direction of development or acquisition). We based our decisionmaking aid on some of the available base model decisionmaking aids in the commercial manufacturing literature, particularly those by Meyer and Lehnerd (1997) and Robertson and Ulrich (1998). These decisionmaking aids are somewhat heuristic, but they encourage, at a minimum, more deliberative processing than decisions based solely on mandates or priorities (or even intuition). We tailored our decisionmaking aid to military needs, because we found that commercial aids sometimes focused more on differentiation through cosmetic differences, for instance, whereas the military should be concerned only with performance.

Commercial decisionmaking aids are prescribed at the design stage, although they can be considered thereafter, most explicitly during redesign or when variants are considered. We prescribe our decisionmaking aid to Army procurers, so that they can better understand their options during development and procurement. Like the commercial decisionmaking aids, our aid works best when the decisionmaker is technically informed and objective about the options. We realize that the Army often procures systems after they have been designed and that suppliers are often sensitive about releasing proprietary information, but the adoption of a decisionmaking aid implies that the decisionmaker will intervene earlier in the product life cycle and with sufficient information, even if such behavior breaks with previous norms. It is true that the Army often procures items whose performance is uncertain. We do not claim that a decisionmaking aid will guarantee perfect decisions when the information is imperfect. It will, however, add rigor if the alternative is to rely on intuition or singular priorities.

Figure 5.1 is a graphical representation of the decision aid we developed. It has four separate plans: the model plan, the differentiation plan, the commonality plan, and the base model plan. Working through the sequence and decision criteria in these plans is important to avoid the problems in commonality we found in our case studies and literature review. Each part of the decisionmaking aid plays a role:

- The model plan determines the models needed by linking capabilities to systems. This plan identifies key capabilities and prevents "commonality by fiat," with its resulting difficulties.
- The differentiation plan determines the critical features of the model, i.e., those key capabilities that need to be given priority in any common system. This plan ensures that "commonality mediocrity" (reducing capability requirements in order to achieve commonality) does not occur, with its ensuing operational shortfalls.
- The commonality plan then determines which components should be made common. This plan reduces the potential for excess capability and "capability greed" (adding capabilities beyond requirements), with its negative cost consequences.
- The base model plan determines whether the number of common components is sufficient to establish a common base model.

Figure 5.1
Capability-Based Commonality Decisionmaking Aid



NOTE: The shapes in the figure represent the transition through the application of the decision aid from requirements with unknown physical attributes (the cloud question marks), to known features (the varying geometric shapes), to common components potentially based on a common platform (the common rectangle with varying shapes on top of it).
RAND *MG719-5.1*

Below, we discuss each plan in detail.

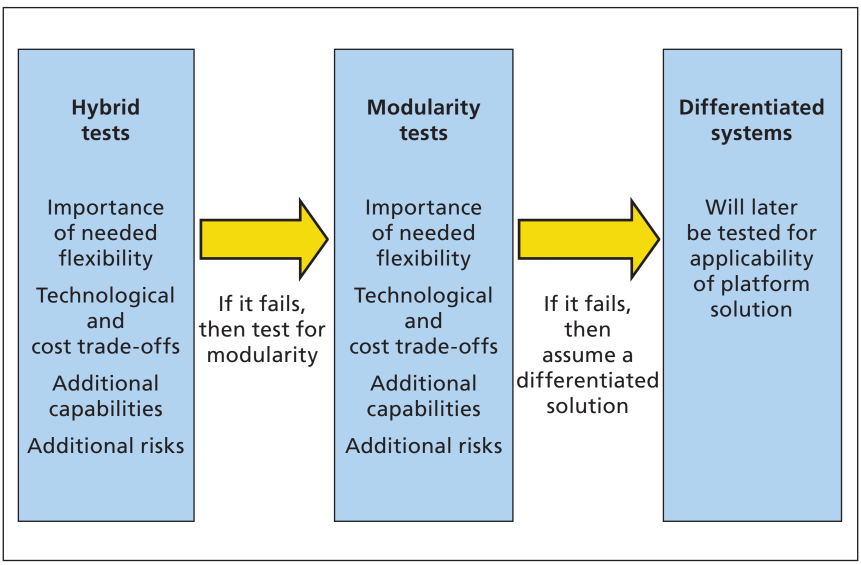
Model Plan

In the first step, the developer should define the requirements, list the capabilities that would meet those requirements, and then make decisions about which capabilities should be hybridized, modularized, or differentiated. The capabilities remaining "differentiated" at the system level will not necessarily remain differentiated at the component level. Instead, they will be carried over to the second step for further review. For instance, an infantry-carrying vehicle offers a capability (carrying) that is not really associated with any particular component. As Table 2.1 and its accompanying discussion indicated, family, hybrid, modular, and differentiated systems present different technological capabilities (for example, range, accuracy, speed) and force employment capabilities (flexibility, tactical changes). Generally, the hybrid solution offers the most ready operational flexibility but can incur the most capability trade-offs. Since the hybrid case is generally the most limiting, it is tested first. (It is handy, but not practical, to have a weapon version of a Swiss Army knife if the trade-offs and costs are too high.) After testing for hybridization, it is appropriate to test then for modularity and lastly differentiation. Figure 5.2 shows the decision flow.

A hybrid solution is indicated if the following is true:

- The capabilities are operationally interdependent. For instance, an IFV hybridizes an armored personnel carrier and its armed variants, allowing the IFV to provide fire support to dismounted infantry.

Figure 5.2
Model Plan Decision Flow



RAND *MG719-5.2*

- The hybrid outperforms nonhybrids in their primary functions. If hybrids under-perform nonhybrids in their primary functions, they may generate new operational risks. Walker (1987, p. 2) noted that "most weapons, like most aircraft, are either highly specific and specialized for one narrow purpose or, alternatively, are heavily compromised in the search for greater flexibility." For instance, "multirole aircraft" were supposed to replace fast, fragile fighters and slow, heavy ground attack aircraft. Fighter aircraft should be fast and agile and should carry smaller caliber guns that can fire large amounts of ammunition, since aircraft are difficult to hit but comparatively fragile platforms. By contrast, ground attack aircraft should be slower, since tighter turning circles and a slower approach are advantageous during ground attack, and they should carry larger caliber guns whose ammunition can harm robust ground targets. The F-15 and F-16 air superiority fighters are fast and armed with a 20-mm multibarrel cannon. By contrast, the A-10 Warthog ground attack aircraft is slower and carries a multibarrel 30-mm cannon. The Panavia Tornado multirole aircraft carries a compromise—a 27-mm cannon—and its speed falls between the A-10 and the F-15 or F-16 (Walker, 1987, pp. 3–5). Multirole aircraft are increasingly popular, and some, most notably the F/A-18 and the Eurofighter, are able to offer different role capabilities (air-to-air combat, ground attack, electronic countermeasures, and even refueling in air) that sometimes outperform their more specialist predecessors. Ideally, hybrids should outperform the specialist predecessors that the hybrid is intended to replace. Different types of weapons offer different competitive advantages, which require appropriate metrics. For instance, grenade launchers and rifles offer different weapon effects. The performance of the former should be measured at least in terms of throw-weight and blast radius, which are not appropriate measures of the rifle's performance. A hybrid rifle/grenade launcher must be measured as both a rifle and a grenade launcher.
- The hybrid gains capabilities beneficial to nonhybrids. For instance, a hybrid tank/personnel carrier gains a rear crew access point, which is useful if the crew needs to escape or wants to

mount the tank without being exposed to enemy fire from the front. However, a rear crew access point is associated with a front-mounted engine, which offers disadvantages such as frontal heat signature and thermal disruption of aiming devices.

- The extra cost of the hybrid outweighs the collective cost of nonhybrids. If the key component allowing hybridization is cheap and easy to add, then the hybrid is an efficient, good choice. For instance, the German 88-mm antiaircraft antitank gun (1937) was fitted with an optical sight, while the British 3.7-inch antiaircraft gun worked off radar data. (The latter was also nearly four times heavier.) Thus, while the German gun could attack airborne or ground targets without modification, the British gun could only attack airborne targets and only in conjunction with radar. By contrast, if the hybrid is expensive and its benefits are ambiguous or are outweighed by new disadvantages, the hybrid is clearly a poor choice. For instance, the U.S. Shillelagh hybrid gun/missile system offered operational flexibility to the tanks on which it was mounted, since it could fire both antiinfantry shells and antitank missiles. The system was fitted to first the M551 Sheridan tank (first deployed in 1968), which is remarkable as an air-deployable tank. However, the Sheridan was a poor antitank weapon. First, its gun was unusually large in caliber for such a light vehicle. Its recoil was transferred to the chassis, knocking the gun off target and creating enough motion, smoke, and dust to give away its firing position, at which point the Sheridan was an easy target for more conventional tanks. Second, the gun's muzzle velocity was low, with the result that it was less accurate than most tank guns. Third, its ammunition was large and the vehicle was small, with the result that the ammunition stowage was too low for most missions. In retrospect, the hybrid gun/missile system did not perform either of its hybrid roles (antiinfantry and antitank) well enough to justify procurement.[1]

[1] The weapon suffered additional design problems. Smoldering residue from the case-less cartridge and the ineffective breech scavenger fouled the barrel. The electrical firing system

- The nonhybrid is no longer operationally necessary. Even if the hybrid does not perform as well as nonhybrids in their specialist roles, the hybrid may be preferred if its inferior performance is no longer considered operationally necessary. For instance, at the end of the Second World War "automatic rifles" or "assault rifles" began to replace both submachine guns and bolt-action rifles as infantry combat ranges declined.
- Hybrids prevent the enemy from targeting distinguishable nonhybrids. Consequential targets include critical nodes, such as command and artillery observation variants, high-casualty targets, such as personnel carriers, and the most threatening variants, such as the antitank variants (Simpkin, 1982, p. 31).
- The hybrid's new operational risks are acceptable. Hybrids may also generate new operational risks never faced by the nonhybrids. For instance, an IFV must expose itself to direct fire whenever it wishes to utilize its direct fire weapons, while armored personnel carriers must expose themselves to enemy fire only to move from one (hidden) location to another.

If personnel do not need all the capabilities all the time, the system should be modularized rather than hybridized. Similar tests concerning flexibility and trade-offs need to be applied to the modular case as well. If the hybridization or modularization would degrade the primary capabilities or result in excessive costs, then differentiated models are needed.

Differentiation Plan

While the first step separated capabilities between models and focused on the system level, the second step further defines the attributes of each model and focuses on the component level. It is concerned with identifying attributes that are critical to the model's function and are

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and electrical turret traverse often failed, particularly in wet weather (Sorley, 1999, pp. 333–334).

cost-effective. In short, this step determines which components truly need to be unique or differentiated in order to retain the model's differentiated capabilities. If the model's differentiating attributes are not found justifiable, the model may be abandoned and its capabilities reconsidered in step one.

First, a completely differentiated design is identified, the projected cost of which should be regarded as the model's upper cost bound. Then the developer must identify the lowest performance limits needed to ensure the model's effectiveness. Note that this identification is often limited to the requirements stage in most other design strategies. Since differentiation suggests specialization and expense, our second step checks the model's trade-offs and cost-effectiveness.

In the marketplace, competitive differentiation depends on successful specialization while lowering costs (Kim and Mauborgne, 2004). Reducing costs at the same time as differentiation mitigates the threat of new, lower-cost competitors. Another way of expressing this principle in a way that is useful to cost-conscious Army procurers is to ask whether the item outperforms yet undercuts most competitors. For instance, the German Leopard 1 and Leopard 2 have been the most popular tanks for import internationally since the British Centurion. The Leopard tanks are popular because their performance surpasses or at least approaches that of most competitors while their cost does not. For instance, the new (German) Leopard 2A6 and (U.S.) M1A2 SEP main battle tanks were introduced recently, at around the same time, with similar performance, even though the former costs about two-thirds of the latter.

Commonality Plan

This third step is concerned with identifying components that can be shared with other models. These decisions should be guided by the cost analysis and the training impact analysis demonstrated in Chapter Three. The process results in a group of potential common and interchangeable components within models, within an enterprise, and with commercially available components. Remaining uncommon items are then considered for interchangeability. Remaining items are then considered for interoperability improvements. Finally, differentiation is rechecked to determine whether critical capabilities are being surrendered to commonality, which we warned against in Chapter Two.

Base Model Plan

Having identified which components should be common, this fourth and final step considers whether a sufficient number of components can be shared to warrant development of a base model. Although the development of a base model may be seen as an economic decision, it has operational impacts as well, since the development of a base model can allow for increased operational capability and reduced logistics burden. Even at this stage, the designer should still consider differentiation once again. For example, differentiation might be the preferred option if a variant would lack required capabilities or performance if it conformed to the base model. The proportion of each model's potentially common components should reach some part count threshold. (A popular commercial threshold is 50 percent, although thresholds can be arbitrary and may neglect the importance of making common components that are logistically burdensome or expensive to procure, as described in Chapter Three. Many decisionmakers prefer to focus on common key components, such as a common drive train and wheelbase.) Numerical commonality indices alone can be deceiving in assessing whether or not a common family exists. In the TFX case discussed earlier, the Boeing design had 60 percent commonality between the Navy and Air Force but was considered two separate planes, because of differences in the wing, fuselage, and tail sections. Capability could be added to an existing base model through line extension:

- Identify a base model.
- Identify a standard configuration.
- Identify an order of development for subsequent variants.
- Predict technology availability.
- Plan development life cycle.

- Predict competitor life cycles.
- Plan further development life cycle (additional potential models).
- Check the balance between commonality and development:
  - For example, ensure sufficient space, power, and flexibility for future development.
- Check balance with differentiation:
  - Abandon the common base model if it limits a variant's critical capabilities.

This decisionmaking aid has components that are rigorous and analytical but has aspects that rely on the judicious application of subject matter expertise. The procurer can use this decisionmaking aid to inform the requirements and to audit subsequent design and development. The designer can use this decisionmaking aid to choose between design strategies and balance the inevitable trade-offs during the design process. And the logistician, trainer, and operator can use the aid to inform the relevant trade-offs and monitor the design process from their perspectives.

CHAPTER SIX

Recommendations

This report makes a detailed analysis of the effects of commonality on key areas of concern to the Army, primarily costs, operations, and training. In addition, we make the following four broad recommendations:

The Army should determine *which* specific components should be made common through objective and informed analysis. Specifically, the Army should assess existing levels of component commonality and determine where efforts should be focused to reduce system costs and the logistical footprint. The Army should develop preferred commonality metrics, similar to the metrics used in this document or those used by exemplary commercial companies, to examine the existing level of component commonality in the Army and its resultant cost and logistical burden.

The Army should determine what organizational changes need to be made to determine whether the desired level of commonality is achieved. Engineering, procurement, and operations personnel often have conflicting interests that, without key factors such as counterbalancing organizational oversight and appropriate incentives, do not automatically lead to component commonality. The Army needs to determine what organizational changes it should undertake to motivate commonality.

The Army should adopt a capability-based commonality decisionmaking aid, of the type discussed in Chapter Five, in order to better guide decisions about concept development, design, and procurement. Procurers should be objective and technically informed about their options; this prescription may require departures from previous norms. For instance, engineers or fleet managers, rather than users, could take a stronger role in procurement decisions and procurers could intervene earlier in the product life cycle. Determining whether to set a requirement for a certain system type requires that the decisionmaking processes be carefully designed to allow commonality trade-offs and benefits to be revealed. Processes and doctrine set up for existing systems may not effectively predict how a new technology will be used. User-based testing, through either rapid prototyping or simulation, is one method through which the unpredictability of the effects can be assessed.

To help accurately assess the impact of commonality on training, we recommend the use of an appropriate and structured methodology such as the TIE method. As we have shown, commonality does affect training, but the outcomes are highly dependent on the specific type of commonality under consideration and the specific components to be made common. A structured approach combined with the input of subject matter experts is necessary to accurately assess the effects. Relying on a nonstructured approach is likely to produce only order-of-magnitude estimates.

Bibliography

Alkire, Brien, John Birkler, Lisa Dolan, James Dryden, Bryce Mason, Gordon T. Lee, John F. Schank, and Michael Hayes, *Littoral Combat Ships: Relating Performance to Mission Package Inventories, Homeports, and Installation Sites*, Santa Monica, Calif.: RAND Corporation, MG-528-NAVY, 2007. As of February 2008: http://www.rand.org/pubs/monographs/MG528/

Anderson, John R., Daniel Bothell, Michael D. Byrne, Scott Douglass, Christian Lebiere, and Yulin Qin, "An Integrated Theory of the Mind," *Psychological Review*, Vol. 111, No. 4, 2004, pp. 1036–1060.

Anonymous, "Stoner-63 Rifle Grenade," *Marine Corps Gazette*, Vol. 50, No. 2, February 1966, p. 59.

Army Infantry School, "*Small Arms Weapon Systems,*" Fort Benning, Ga.: Army Infantry School, December 1965.

ATR (Aerei da Trasporto Regionale or Avions de Transport Régional), "ATR 42-500 and ATR 72-500, the Optimum Choice for Regional Operation," Blagnac, France: ATR Headquarters, n.d.

Biddle, Stephen, *Military Power: Explaining Victory and Defeat in Modern Battle*, Princeton, N.J.: Princeton University Press, 2004.

Bolkcom, Christopher, *Joint Strike Fighter (JSF) Program: Background, Status, and Issues*, Washington, D.C.: Congressional Research Service, January 11, 2002.

Brant, Robert E., "Evolution of a Weapons Family," *Marine Corps Gazette*, Vol. 49, No. 2, February 1965, pp. 41–44.

British Army, garrisons Web site, n.d. As of October 29, 2007: http://www.army.mod.uk/garrisons/bordon/seme/phase_2_training/vehicle_mechanic_a_trade_module.htm

Brockelman, S., D. Jones, and K. Poe, *Product and Technology Platforms,* Washington, D.C.: Research & Technology Executive Council, August 2002.

Canadian Army, recruiting Web site, October 29, 2007. As of February 2008: http://www.recruiting.forces.gc.ca/v3/engraph/jobs/jobs.aspx?id=411&bhcp=1/

Chopra, Sunil, and Peter Meindl, *Supply Chain Management: Strategy, Planning, Operation,* Upper Saddle River, N.J.: Prentice Hall, 2007.

Dockery, Kevin, *Weapons of the Navy SEALs*, New York: Berkley Trade, 2004.

Eby, Jeffrey L., "M203 or Rifle Grenade?" *Marine Corps Gazette*, Vol. 87, No. 3, March 2003, pp. 48–53.

FM 3-22.9 and FM 3-22.68, *see* U.S. Army, 2003a and 2003b.

Gibbs, Joseph W., "Lima Company and the Stoner 63A Weapon System," *Marine Corps Gazette*, Vol. 84, No. 1, January 2000, pp. 68–73.

Government Accountability Office [GAO], *Separate Army and Air Force Airborne SINCGARS Programs May Be Uneconomical*, Washington, D.C.: GAO, GAO/NSIAD-85-50, January 1985.

Grantham, David S., *The Quest for Commonality: Comparison of the TFX and JSF Programs*, thesis, Maxwell Air Force Base, Ala.: School of Advanced Airpower Studies, Air University, 1997.

i2 Technologies US, Inc., *i2 Component and Supplier Management,* Dallas, Tex.: i2, 2004. As of May 21, 2007:
http://www.i2.com/assets/pdf/PDS_csm_v61_pds7203_0404.pdf

ISO Group, Integrated Logistics Analysis Program (ILAP), output from January 1 2003–September 9, 2005, West Melbourne, Fla.: ISO Group, n.d.

Johnson, Dana, *Big Bang: Mini Bang 2—The Deadliest Weapon That Never Was*, Alternate Realities Publications, 2003.

Johnson, H. Thomas, and Anders Broms, *Profit Beyond Measure: Extraordinary Results Through Attention to Work and People*, New York: Free Press, 2000.

Kennedy, Harold, "Marines Extend Program to Keep Aging Vehicles in Service," *National Defense*, March 2006, pp. 38–39.

Kim, W. Chan, and Renée A. Mauborgne, "Blue Ocean Strategy," *Harvard Business Review*, Vol. 82, No. 10, October 2004, pp. 75–84.

Klein, Gary A., *Sources of Power: How People Make Decisions*, Cambridge, Mass.: MIT Press, 1998.

Klein, Gary, and Holly C. Baxter, "Cognitive Transformation Theory: Contrasting Cognitive and Behavioral Learning," paper presented at the Interservice/Industry Training, Simulation, and Education Conference, Orlando, Fla., December 2006.

Labro, Eva, "The Cost Effects of Component Commonality: A Literature Review Through a Management Accounting Lens," *Manufacturing Service Operations Management*, Vol. 6, No. 4, Fall 2004, pp. 358–367.

Laird, John E., Allen Newell, and Paul S. Rosenbloom, "SOAR: An Architecture for General Intelligence," *Artificial Intelligence*, Vol. 33, No. 1, September 1987, pp. 1–64.

McManus, H. L., A. Haggerty, and E. Murman, "Lean Engineering: Doing the Right Thing Right," Proceedings of the 1st International Conference on Innovation and Integration in Aerospace Sciences, Queen's University Belfast, Northern Ireland, UK, August 2005.

Merle, Renae, "Problems Stall Pentagon's New Fighting Vehicle," *Washington Post,* February 7, 2007, p. A01.

Meyer, Marc H., and Alvin P. Lehnerd, *The Power of Product Platforms: Building Value and Cost Leadership,* New York: Free Press, 1997.

Newsome, Bruce, Matthew W. Lewis, and Thomas Held, *Speaking with a Commonality Language: A Lexicon for System and Component Development,* Santa Monica, Calif.: RAND Corporation, TR-481-A, 2007. As of February 2008: http://www.rand.org/pubs/technical_reports/TR481/

Nobelius, D., and N. Sundgren, "Managerial Issues in Parts Sharing Among Product Development Projects: A Case Study," *Journal of Engineering and Technology Management*, Vol. 19, No. 1, March 2002, pp. 59–73.

Nuffort, M. R., *Managing Subsystem Commonality,* Cambridge, Mass.: MIT, 2001.

Peltz, Eric, Patricia Boren, Marc Robbins, and Melvin Wolff, *Diagnosing the Army's Equipment Readiness: The Equipment Downtime Analyzer*, Santa Monica, Calif.: RAND Corporation, MR-1481-A, 2002. As of June 2008: http://www.rand.org/pubs/monograph_reports/MR1481/

Percy, Stephen, "Target Small Arms," *Marine Corps Gazette*, Vol. 49, No. 5, May 1965, p. 60.

Perera, H.S.C., Nagen Nagarur, and Mario Tabucanon, "Component Part Standardization: A Way to Reduce the Life-Cycle Costs of Products," *International Journal of Production Economics*, Vol. 60–61, April 1999, pp. 109–116.

Robertson, David, and Karl Ulrich, "Planning for Product Platforms," *Sloan Management Review,* Vol. 39, No. 4, Summer 1998, pp. 19–31.

Sheffi, Yossi, *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage,* Cambridge, Mass.: MIT Press, September 2005.

Simpkin, Richard E., *Antitank: An Airmechanized Response to Armored Threats in the '90s,* London, UK: Brassey's, 1982.

Simpson, Timothy W., Zahed Siddique, and Jianxin Jiao, eds., *Product Platform and Product Family Design: Methods and Applications*, New York: Springer, 2006.

Singley, Mark K., and John R. Anderson, *The Transfer of Cognitive Skill*, Cambridge, Mass.: Harvard University Press, 1989.

Sorley, Lewis, "Adaptation and Impact: Mounted Combat in Vietnam," in George F. Hofmann and Donn A. Starry, eds., *Camp Colt to Desert Storm: The History of U.S. Armored Forces*, Lexington, Ky.: University Press of Kentucky, 1999, pp. 324–359.

Stevens, R. Blake, and Edward C. Ezell, *The SPIW: The Deadliest Weapon That Never Was*, Cobourg, Canada: Collector Grade Publications, 1984.

———, *The Black Rifle: M16 Retrospective*, Cobourg, Canada: Collector Grade Publications, 2004.

Subramaniam, Mohan, and Keoy Hewett, "Balancing Standardization and Adaptation for Product Performance in International Markets: Testing the Influence of Headquarters—Subsidiary Contact and Cooperation," *Management International Review*, Vol. 44, No. 2, 2004, pp. 171–194.

Thonemann, Ulrich W., and Margaret L. Brandeau, "Optimal Commonality in Component Design," *Operations Research*, Vol. 48, No. 1, January–February 2000, pp. 1–19.

Treacy, Michael, and Fred Wiersema, *The Discipline of Market Leaders: Choose Your Customers, Narrow Your Focus, Dominate Your Market*, Boston, Mass.: Addison-Wesley Publishing, 1994.

U.S. Army, Web site, n.d. As of February 2008:
http://www.goarmy.com/

———, *Officer Personnel Management Information System (OPMIS),* "Total Army Personnel Data Base, October 2004 to September 2005," Alexandria, Va.: Commander, U.S. Army Human Resources Command, n.d.

———, *Rifle Squad and Platoon Evaluation Program 22 May–31 July 1961, Annexes A-I*, Fort Benning, Ga.: Army Infantry School, October 23, 1961.

———, Field Manual (FM) 3-22-68, *Crew-Served Machine Guns 5.56-mm and 7.62-mm,* Washington, D.C.: Headquarters, Department of the Army, January 31, 2003a. As of June 2008:
http://www.globalsecurity.org/military/library/policy/army/fm/3-22-68/index.html

———, Field Manual (FM) 3-22.9, *Rifle Marksmanship M16A1, M16A2/3, M16A4 and M4 Carbine,* Washington, D.C.: Headquarters, Department of the Army, April 24, 2003b. As of June 2008:
http://www.globalsecurity.org/military/library/policy/army/fm/3-22-9/index.html

———, *Table of Organization and Equipment,* 87300G000, Heavy Brigade Unit of Action, March 18, 2004.

U.S. Congress, *Hearings Before the Special Subcommittee on the M-16 Rifle Program of the Committee on Armed Services,* House of Representatives, Ninetieth Congress, First Session, May 15, 16, 31, June 21, July 25, 26, 27, August 8, 9, and 22, 1967, Washington, D.C.: U.S. Government Printing Office, 1967.

Walker, J. R., "Air-to-Surface Weapons," in K. Perkins, ed., *Weapons and Warfare: Conventional Weapons and Their Roles in Battle,* London, UK: Brassey's, 1987, pp. 1–54.

Weller, Jac, *Weapons and Tactics: Hastings to Berlin,* New York: St. Martin's Press, 1966.